Critical Reading of Software

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Critical Language for Software

The name of the architect Christopher Alexander is perhaps better known in programming circles than among architects, so he makes for the perfect opening of a text that aims to find new links between the world of architecture and the world of software. But let me be clear that I reference Alexander mainly to highlight a question that he posed about the software practice, rather than to draw inspiration for better software design from his work, a task already done by others.[1]

The question I want to refer to was raied by Alexander in a keynote that he delivered in 1996 at the annual ACM Conference on Object-Oriented Programs, Systems, Languages and Applications (OOPSLA). This was not an incidental invitation. By the mid-1990s, Alexander's ideas on pattern languages and design patterns were already influential in the computer science and software engineering circles and many of those involved in bringing Alexander's ideas into the world of software were regular participants at OOPSLA.

In his keynote, Alexander talked about his lifelong quest for creating living structures in the world, i.e., beautiful structures where each element is in harmony with each other, structures that evolve well and reflect natural inclinations of their human inhabitants. In the last part of his talk, Alexander called upon the attendees to take responsibility for the built environment and tackle the problem of generating living structures. As Alexander pointed out, the idea of generative process is natural to computer scientists and so they are well equipped for the task.

Alexander commented on a perceived "undercurrent of unease as to where all this—software design—is going". In a "very direct and blunt" comment, he suggests that:

> It could be thought that the technical way in which you [computer scientists] currently look at programming is almost as if you were willing to be "guns for hire." In other words, you are the technicians. You know how to make the programs work. "Tell us what to do daddy, and we'll do it." That is the worm in the apple.

One could conclude that computer scientists and programmers share their predicament with architects who, as argued by Charles Jencks[2] "have little power, [and] are not in any better position to command what is built." Perhaps like architects, computer scientists and programmers being "fairly low in the chain of command and needing jobs, are prone to compromise with the state and the establishment."

There may be some truth in that, but I believe this is not the entire truth. On a more basic level, programming, computer science and software development lack the critical language that is needed for thinking about the problem. In other words, regardless of whether we have the power to command what is built, we do not know how to effectively critically question what is built, how to imagine alternatives, and how to ironically poke at the undesirable characteristics of what is being built.

This text is an attempt to develop such critical language of software. To do so, I will draw on a number of architects and architectural critics. Their work provides an inspiration for what, I believe, is needed for software. Some of those critiques are in the form of written text, but more notably, architects also use building plans and buildings themselves to raise important points about architecture. I believe we, programmers and computer scientists, similarly need to find ways of designing software that not only fulfils a certain function, but also raises critical questions. I acknowledge a certain irony in my effort. What you are looking at is itself text and not a piece of software.

Although I started with Alexander's comment and I share his belief that programmers and computer scientists should not accept the role of "guns for hire," my thinking follows a different route than that suggested by Alexander—one that would likely not make Christopher Alexander himself very happy.[3] Rather than seeking a way of building that achieves a living structure, I turn to debates on architecture that emerged from post-modern critical architecture and debates about it.

Even if our sole goal as programmers and computer scientists was to produce "living structures" in the world, I do not think we can achieve this without first having a critical language that lets us reflect on our work, criticise existing approaches, deconstruct our creations and look for alternative arrangements.

In other words, I believe there is a value in exploring disharmony[4] and in using a critical language of architecture—or in my case of software—to criticise the state of the discipline and imagine new ways of thinking and new ways in which software can support social structures. Although I mainly look to writing on post-modern ar chitecture for sources of inspiration, the idea of using buildings to question established order is by no means new. We can trace similar ideas to the rise of modernism in Europe following the First World War when some architects "overwhelemed by the nightmare of industrialization (...) briefly speculate on alternative condition":[5]

> It is not the crazy caprice of a poet that glass architecture will bring a new culture. It is a fact. (...) Therefore the European is right when he fears that glass architecture might become uncomfortable. Certainly it will be so. And that is not its least advantage. For first of all the European must be wrenched out of his coziness.

On the next couple of pages, I will look at two themes from post-modern architecture that highlight some of the aspects of the critical language developed by architects that I hope to create for software. I will then return to methodological problem of how such language can be structured.

The Ironical Column

To illustrate some of the ways through which architects use architecture to communicate, I start with the most basic structural element of classical architecture, the column. Figure 1 shows several uses of columns, starting from the ancient Parthenon built in Athens in 5th century BC (bottom left) followed by four examples that include a variety of references to the classical column.[6]

Figure 1: Six different uses of columns in architecture. (1) Unironical use of the column in the 1935 neoclassical building of the US National Archives, (2) Supporting pilotis in Le Corbusiers 1931 Villa Savoye, (3) The Parthenon in Athens built in the 5th century BC according to the Doric order (4) Adolf Loos' playful reference to the Doric column in a 1922 entry for the Chicago Tribune Tower Competition, (5) Hans Hollein's ironical Facade of Morphed Columns, at the 1980 Venice Architecture Biennale, and (6) Robert Venturi's "ironic" column from the 1977 addition to the Allen Memorial Art Museum.

Neoclassical architecture, which gradually grew in prominence in the late 18th century, looks back to the Classical past. It sees it as a source of pure geometric order with ideal proportions and symmetry. Such references to the ancients should not be unexpected. At the start of the 17th century, Aristotle and other ancient philosophers were seen as the source of truth that was partly lost and needs to be recovered, but that was already fully known to the ancients.[7] The scientific revolution of the 17th century gradually changed perspective on the ancients in what was becoming experimental science, but it should not be a surpirse that architects of the 18th century were still looking back to ancient structures that were becoming rediscovered and better understood at the time. Neoclassical architecture remained influential after the 18th century, but its meaning slowly shifted. It turned from an attempt to rediscover and recreate simple, purely geometrical structures to an idealized style that emphasises tradition. The use of the style for many US federal buildings is thus a reference to the values that the style encompasses.[8]

The modernist Villa Savoye designed by Le Corbusier also looks back to the Classical past, but it does so in a different way. Rather than directly copying the style and order of the ancient Greek temples, the building is a reinterpretation of the ideas of a Greek temple.[9] It reimagines the ideal structure of Greek temple based on geometric principles (using the golden ratio), but replaces ancient Greek columns with minimalistic modernist pilotis. Following the modernist focus on function, Le Corbusier's design uses pilotis to give prominence to the automobile (parked on the ground floor). Although the same historical reference is present in Villa Savoye, it is used at a more conceptual level and is not immediately apparent.

The importance of the column as an icon representing a certain style of architecture was well understood by other modernist architects, including Adolf Loos who is best known as the author of the modernist manifesto "Ornament and Crime", first presented as a lecture in 1910. In his entry for the Chicago Tribune headquarters competition in 1922, Loos made yet another reference to the ancient Greek temple and shaped the entire building as a giant Doric column. Loos himself did not view the column in his design as ornamental and instead saw it as supporting the public nature of the building with appropriate symbolism.[10] The structure of the building itself here becomes the symbol in a way that is reminiscent of later post-modernist works where construction patterns and material textures themselves become ornament.[11] Despite being rooted in the modernist thinking, the Chicago Tribune Tower project became an inspiration for later post-modern architects who make, more or less subtle, historical references in an ironic way. They will include columns in their buildings to indicate that they recognize being a part of architectural culture and tradition, even if they no longer need columns as structural support mechanisms.

A good illustration of the ironic reference is the facade created by Hans Hollein for the 1980 Venice Biennale. The event took place in Corderia of the Arsenale, a large historical building itself featuring supporting columns. The participants of the Biennale were asked to design a facade for their exhibition that would cover (and hide) the historical structure of the Corderia. Hollein did the exact opposite. He complemented two columns of the Corderia with a range of ironical forms of columns. One was a bushy tree cut into the shape of a column, while another was a scaled-down version of Loos' Chicago Tribune Tower. The entrance into the exhibition was under a hanging fragment of a column, which clearly lost its original structural function, but gained a different function as an exhibition entrance. Here, the ironical use of the architectural language is direct and understandable.[12]

Hollein's entry addressed the theme of the Biennale, "The Presence of the Past" in a way that is funny and ironic, but sends a clear message about history and continuity of architecture. It also illustrates the changing function of a column from supporting structure to a decoration. Moreover, the ironical style of the presentation, shared with many other post-modern architectural works, makes the message accessible and engaging for broader public. Hollein's facade is interesting for yet another reason. It uses architectural language to communicate architectural ideas, but it is neither text, nor a building. As we will see repeatedly, built structures such as stage sets or monuments are often interesting media through which critical architectural ideas can be expressed.

The column takes yet another form in the addition to the Allen Memorial Art Museum designed by Robert Venturi in 1977. The extension itself is based on an idea that Venturi refers to as the "decorated shed". The basic structure and spatial disposition of the building itself is simple and serves its function which was, in part, to provide more storage space. Any symbolic, cultural and aesthetic meaning is provided "by modifying the basic shell by means of design decisions of a second order."[13] One such second-order decision is the addition of isolated iconic elements, such as the mock Ionic column that marks the building as cultural institution. In a way, the column serves similar role as the neoclassical architecture of the US National Archives, but is here added merely as an ironic decoration. The association of ancient Greek columns with important public buildings remains, but the story is told in a very different way.

Towards Critical Software

In my attempt to translate the critical langauge of architecture into the world of software, I will alternate between two modes of working. First, I will reinterpret existing practices in software development and computer science in light of the architectural theory. Second, I will suggest how we could more deliberately follow in the footsteps of architects and create new software artifacts that express critical points about software.

In other words, can we follow post-modern architects and embed criticism as a first-class element in software practice, rather than leaving it to a second-class (and largely optional) critical writing?[14] We can also look to post-modern architects for initial ideas of what such critical software can say. The architectural style known as eclecticism makes funny references such as Hans Hollein who decorated his Austrian Travel Agency office with metalic palm trees and broken Greek column.[15] The appeal of the style is not just its straightforward humour, but the fact that it is understandable and can communicate with wider audience. Similarly, post-modern architects have used contextualism to highlight important characteristics of the environment they work in or use references to suggest alternative social organization.

Looking at existing software practices, we can imagine how the above arhictectural ideas can apply to basic structural elements from which software is built. One such element may be the data structures around which software is structured.[16] Data structures in software are arguably even more fundamental than columns in architecture, because any software that works with data needs to store the data in some way. The limitation of this metaphor is that, unlike columns which are typically visible, data structures are typically hidden from the end-user. There also is no singular classical model of data structures, although a number of models fit a similar role. These include the relational model of databases, flat memory model of low-level programming languages and data types that model data as collections of nested records.[17]

We can use the architectural metaphor to talk about the differnt kinds of classical models of data structures. Whereas the relatively expressive language of the relational model or the nested records model could be linked to different kinds of classical columns, the minimalistic models of flat memory or nested lists of the Lisp programming language are more akin to modernists undecorated and purely functional pilotis.

When the data structures are used to store data, they serve the original intended purpose, just like columns functioning as supporting structure. But equally, there are software systems where data structures are used more as rhetorical elements, intended not for the computer execution of the software, but for the end-user or programmer. One example would be types in the TypeScript programming language. Here, the actual representation of data can be anything permitted by the underlying JavaScript runtime. TypeScript type declarations are mere labels, intended for the human and for the static TypeScript type checker, but they are not enforced or used for checking at runtime. The type declarations still look like a definition of the shape of a data structure (a column), but they no longer play the basic structural function. They are used for paratial checking (a scaffolding around a column?) and as information for the programmer (a purely rhetorical column). A similar case would be the use of data structures in non-relational databases such as key-value stores or document databases. The data stored in such systems in practice has some implicit structure. However, any explicit description of the structure is merely literal. The

```
<CsamlFile xmlns="http://schemas.microsoft.com/winfx/2006/xaml/csaml"
     xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml">
  <NamespaceDeclaration Identifier="MyNamespace">
    <ClassDeclaration Identifier="MyClass" Access="Public">
      <MethodDeclaration Identifier="Main" Access="Public"
          Modifier="Static" ReturnType="{x:Type void}">
        <InvocationExpression MemberAccess="System.Console.WriteLine">
          <InvocationExpression.ArgumentList>
            <Literal Type="{x:Type string}" Value="Hello, CSAML!">
          </InvocationExpression.ArgumentList>
        </InvocationExpression>
      </MethodDeclaration>
    </ClassDeclaration>
  </NamespaceDeclaration>
</CsamlFile>
```

Figure 2: The "Hello world" program written using the C# Application Markup Language (CSAML), conceived by Charles Petzold in an April Fool's post on 1 April 2006.

description may use the language of standard data structures (collections, records, primitive types), but this is not used for representation.

Do certain data structures also have particular symbolic associations, in a manner similar to how the Classical column stands for traditional values, often associated with US federal buildings? I believe this is the case. For instance, the class-based object-oriented programming paradigm is often associated with maintainability. Languages that adopt class-based object-oriented abstractions as their basic data structure do not do so just for practical, but also for symbolical reasons. TypeScript serves to illustrate this again. One of the first books on the language claims that "TypeScript [brings] a level of maintainable structure to JavaScript development through its class and module features."[18] Written in the same year when the language was released, the claim could not rely on empirical experience with the language, but mainly on the symbolic associations of the data structure.

For my last example based on a reference to an existing artefact, I want to show that data structures have already been used to make critical ironical statements. The April Fool's post written by Charles Petzold in 2006 introducing the "C# Application Markup Language" is a illustration.[19] The post introduces a new notation that encodes programs written in the C# language using XML (Figure 2). The post can be seen as an ironical work of contextualism. The post was published in the heyday of the XML format when Microsoft released multiple development frameworks built around XML. As a well-written April Fool's joke, the post made readers think. The post praises the semantic clarity of the XML format and gives various examples that are extremely lengthy and tedious. After a brief puzzlement, most readers realise the joke. But the post makes them wonder about the verbosity and unnecessary overuse of the format at the time.

The C# Application Markup Language example hints at a number of themes that I will further explore later. It is perhaps blatantly funny, but it can still be seen as making a serious point. Moreover, the system that the post describes has never been actually implemented. The post is merely a (very basic) plan for a system. This does not, however, make it any less valuable as critical software. Many interesting pieces of critical architecture have also not been built, yet, they became important references. The Chicago Tribune tower by Adolf Loos is one such case, but even better example would be one of the many architectural

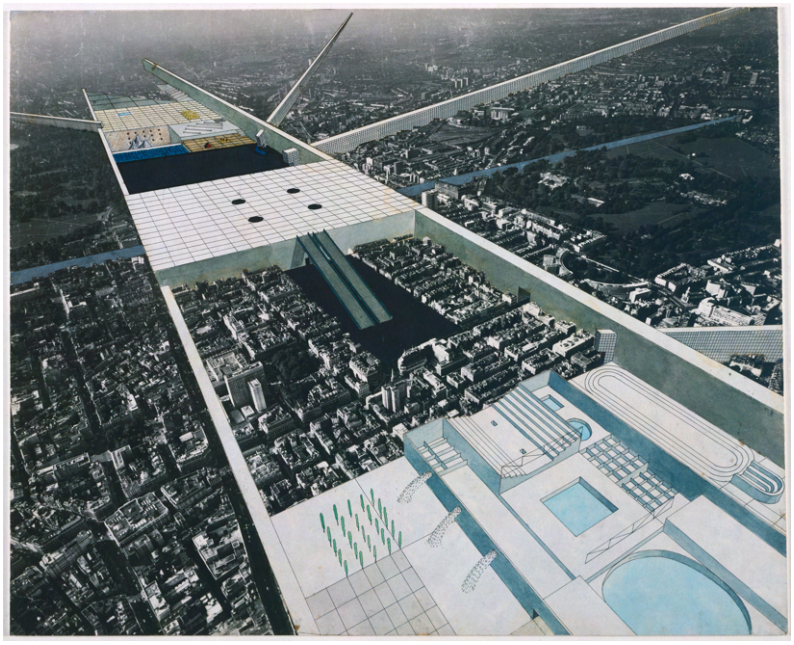


Figure 3: "Exodus, or the Voluntary Prisoners of Architecture: The Strip (Aerial Perspective)" by Rem Koolhaas, Elia Zenghelis, Madelon Vriesendorp and Zoe Zenghelis. The project imagines a walled city of "new urban culture" within the city of London.

projects that use the architectural language to intentionally propose structures that cannot be built. One such project is The Strip (Figure 3) by Rem Koolhaas. The project imagines an enclosed restricted city cutting through London. Although the work was inspired by the situation of West Berlin during the Cold War, the ideas of building a wall to separate cultures can be seen in new (and alarming) light today.

In the subsequent chapters, we will see that hypothetical design proposals, fictional plans that cannot be built or impractical systems are a powerful way of making a point about software systems, just like they are a powerful way of making a point about architecture. The C# Application Markup Language can be seen an example of a much broader class of esoteric programming languages, which are created jokingly, but can be often read as valuable critiques.[20]

As I wrote earlier, I believe that we can take inspiration from the critical architectural language both to analyze existing software systems and projects, but also to come up with new ideas. Some of the references to a column that I discussed earlier make points that may well be applicable to software systems. For example, they may ironically highlight the fact that a column is used for its symbolic value, but not for its original purpose. They highlight the fact that it is no longer needed functionally, even if it is often used for rhetorical reasons. We can imagine a range of similar critical points to be raised about the technical concept of data structures in the context of programming and software systems. If a column is no longer needed as a structural element, what may be the established essential aspect of data structures that is no longer needed?

One of the most established ideas associated with structuring application data is that of information hiding.[21] The argument is that one should separate software systems into components that have a stable public interface and private implementation. If one identi-

Figure 4: The Centre Pompidou "inside-out" building, which keeps all the infrastructure (using green for plumbing, yellow for electricity, blue for climate control, and red for circulation) on the outside to allow flexible and efficient use of the inside space.

fies suitable stable public interface, it is possible to develop the components in isolation, change the implementation or replace individual components as needed. But information hiding has also been criticised.[22] The problem is that predicting what part of the interface should be fixed and what can be hidden is often difficult, especially in the context of software systems whose function evolves and changes over time. Clark and Basman[23] quote the example of MIDI SysEx messages that have, by convention, become a mechanism that exposes the state and can control the operation of musical devices. This enabled MIDI to become a powerful music control platform in a way that could not have been anticipated by the designers of the MIDI interface in the 1980s. Arguably, an even more prominent example would be the web platform, where much of the data structures that the web is built around (HTML, CSS) are also transparent.[24]

So far, most ciritiques of information hiding have taken the form of text. To make the point through the critical language of software, we should design an exemplar piece of software or programming system that reverses the idea of information hiding. In other words, we should expose all the underlying data structures of the software in a way that is akin to how the Centre Pompidou (Figure 4) exposes all the service infrastructure of the building.

In such hypothetical system,[25] all the state of the system would be externalised in a way that allows anyone to see and modify it. To make the point, the system should do this to the extent possible. The accessible state should include all information about the data structures, as well as execution of the system. Depending on the chosen programming paradigm, this may include data of all objects, memory, stack, currently executing instructions etc. The information should also be exposed in a way that makes it available not just to the programmer,[26] but also to the end-user. The system would have to handle

the fact that its state may be modified in inconsistent ways and could either recover as best as possible (akin to how web browsers recover when encountering invalid HTML) or break (likely making an interesting point about the fragility of software systems).[27] The color coding used in the Centre Pompidou offers another interesting idea. If we exposed all data structures of a software system using similar color coding (for different aspects of the system), the system would increase public awareness about what modern software consists of. Thus the project can also fulfil an educational function.

There is, of course, a practical issue of the context in which such project can become reality. It is entirely possible to develop a critical software system only in the form of specification or description, much like Charles Petzold's C# Application Markup Language. However, to explore the consequences of the design—and see how a system can be used in the absence of information hiding—an actual non-trivial working implementation is needed. I will return to this problem later, but architecture has a variety of options. Many architects explore their theories for houses built for their own use or their family.[28] Similarly, programmers and computer scientists often have their own projects to experiment on.

Architecture also often speaks through non-building objects such as stage sets, public monuments, pavilions and follies or exhibitions. Those may not (yet) have obvious equivalents in the world of software and the task of developing critical language of software may involve finding those. Last but not least, new architecture also sometimes emerges in isolated places within a large city, called heterotopias in reference to Michel Foucault.[29] Such isolated spaces, such as prisons, ghettos, amusement parks, or leftover spaces known as terrain vague.[30] I believe we can similarly find a range of atypical pieces of software, which are often deemed as unimportant, but provide space for experimentation. Ad-hoc scripts, demos, spreadsheets, and programs created at hackathons or coding competitions are only a few examples of hterotopias in the world of software.

Formal Grammars of Architecture

In the previous two sections, I focused on ideas that approach architecture from the particular, specifically the structural element of a column. I will now look at ways of developing critical language for architecture starting from the general. I look at a number of works, most notably by Peter Eisenman, that relate architecture to language, art and their formal structures and grammars (Figure 5).

The most direct reference to formal grammar in the context of architecture comes from Peter Eisenman's PhD thesis, completed in 1963 at University of Cambridge. His thesis, "The Formal Basis of Modern Architecture" is concerned with formal analysis of form and formal order in modern architecture. Eisenman suggests that the architectural form can be seen as a problem of logical consistency, rooted solely in the properties of basic structures from which the architectural form arises. The view opposed that of modernists who saw form as arising from function, as well as Christopher Alexander's view put forward in his Notes on the Synthesis of Form.[31] In contrast with modernists:

> Eisenmann saw modernist forms not as simple derivatives of functional needs, but as delineations of the immanent self-referntial properties of architectrue itself, as searches for objective knowledge that lies outside both the architural agent's intentions and the building's uses, and inside the very materials and formal operations of architecture.[32]

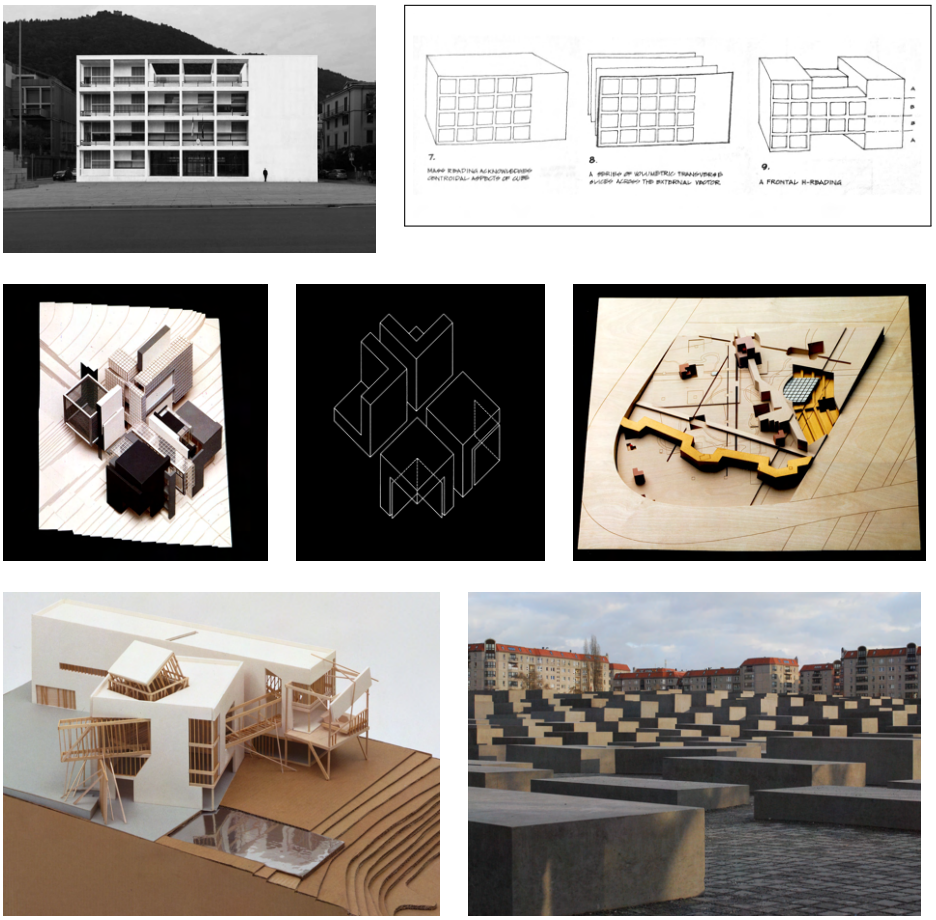


Figure 5: Five different uses of what can be interpreted as a formal language in architecture. (1) Modernist Casa del Fascio in Como, Italy built in 1936 and (2) a formal analysis of the building by Peter Eisenman, (3) model of the House X, also by Eisenman and (4) a diagram illustrating its formal structure based on the L-shape, (5) model from a 1987 project for a garden in the Parc de la Villette by Eisenman in collaboration with Jacques Derrida, (6) model of the unbuilt Familian Residence house by Frank Gehry from 1978, and (7) the Memorial to the Murdered Jews of Europe designed by Eisenman, completed in 2004.

The time was probably right for this kind of intellectual project. Eisenman was influenced by his reading of the linguist Noam Chomsky,[33] who published his first work on formal languages and grammars at the end of the 1950s. The same ideas also contributed to the development of formal grammars of programming languages at the end of the 1950s.[34]

Eisenman's thesis is analytical. He considers the plans of a range of modern buildings, including those by Le Corbusier, Mies van der Rohe and Alvar Aalto, and explains their structure in terms of a number of simple formal principles. Those include three basic kinds of movement systems throughout the building (pinwheel, spiral, echelon), three types of volumetric systems (horizontal planes, vertical planes, plaid) and various interactions between them that lead to distortions of and dislocations in the basic structure.

One building analyzed by Eisenman is the modernist Casa del Fascio in Como designed by Giuseppe Terragni. Eisenman sees the formal structure of the building as the product of "reconciliation between a centroidal plan and a linear site."[35] The form is a hollowed out cube. The cube can be seen as a series of planes, which needs to be acknowledged by the side facades and which imposes a connection between the front and the rear facade. To

accommodate access to the inner courtyard, which results from the centroidal plan, the "negative volume is then dislocated" giving the frontal facade reading of an H-form.

Eisenman's analysis may seem like a curious theoretical exercise, but architects who study the structure or the langauge of architecture had a more fundamental objective. Their aim was to establish autonomous architecture, that is architecture that "opens the internal processes of architecture to their own internal possibilities."[36] In other words, they seek architecture that is not created in response to various external forces (of which there are many), but that is rooted in its own basic (necessary) principles.

Eisenman himself went on to explore various uses of a formal architectural grammar, not just analytically, but also as the basis for new designs in his numbered series of houses, some built and some unbuilt. The House X, for instance, is a critique of "the idea of development from simple to complex"[37] by using the L-shape as the starting point, replacing the conventional cube. The design questions the humanist ideology by disrupting the centrality that is typical of most houses. Where one might expect a hearth or a staircase, there is nothing. The fact that this introduces a degree of disharmony in the project has become contentious issue. While, Eisenman argued that an importnat role of art and architecture is reminding people that "everything isn't all right", Christopher Alexander in a debate said that such design makes him "incredibly angry" and he saw projects that introduce disharmony as "fucking up the world".[38]

In the 1980s, the experiments with architectural language, its grammar and the decomposition of architectural structures took another form. Influenced by the French philosopher Jacques Derrida, architects started to use architectural language to question the basic structures and their conventional meaning. Eisenman himself collaborated with Derrida on a project for a garden in the Parc de la Villette. The proposal eventually developed[39] into a scheme that rescales and overlays a number of different structures including historical state of the site when it was a part of city walls and other projects by Eisenman and his collaborators.

The almost mechanical design method is used to destabilize traditional values of architecture such as its human scale and function. The authors propose to do this by making parts of the park unexpectedly large or small, or by making parts inaccessible. The La Villette project thus uses the architectural language to question the basic assumptions of architecture. The project, again, causes the kind of disharmony that would enrage Christopher Alexander.

In a critical commentary on the Parc de la Villette, Jeffrey Kipnis explained that the point of deconstruction is to "battle with the very meaning of architectural meaning."[40] Because "deconstruction deconstructs the homogeneity, the unity of style" it cannot, according to Jacques Derrida yield to a single architectural style. Yet, this is what, perhaps somewhat inadvertently, happened in the 1980s when the theoretical works of Eisenman got jointly exhibited with more literal or pragmatic works by architects such as Frank Gehry, Zaha Hadid or the Austrian firm Coop Himmelb(l)au.[41]

An early example of what became known as deconstructivist architecture is the series of Frank Gehry's residential designs of the late 1970s and early 1980s. Gehry's work combines experiments with different materials and spatial dynamics with the rejection of the modernist grid.[42] His formal structures are inspired less by grammars of Chomsky, but by avant-garde artists. For example, the "main masses [of his Familian Residence house] form a clearly Supermatists grouping, recalling Malevich's Red Square and Black Square."[43] As noted by Charles Jencks, "Gehry's method of Deconstruction can be quite literal at times,

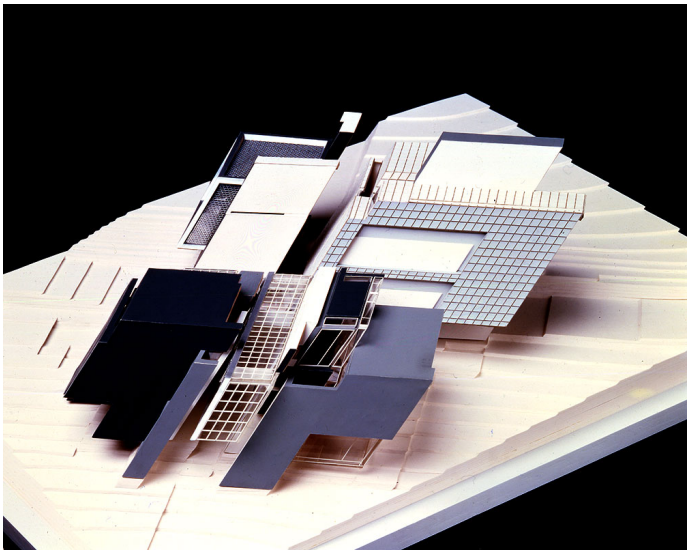


Figure 6: Axonometric model of House X, which is a three-dimensional construction, made to provide the image of a two-dimensional drawing from one particular angle.

since he will smash an existing building into parts, leave elements of his own work unfinished and (...) make an aesthetic virtue of rough, crumbled surfaces."[44] Yet, despite the different aesthetic and conceptualization of the work, there is a clear connection between the work of Eisenman and Gehry. In some of their works, they both try to uncover basic forms that comprise architectural structures and reveal them through distortion.

The formal abstract structure, resulting from the composition of primitive architectural forms, was also the basis for Eisenman's design for the Memorial to the Murdered Jews of Europe, also known as the Holocaust Memorial in Berlin. The same formal mechanisms that were used as a critique of humanism in architecture are used to create an unnerving experience for the visitor.[45] The abstract form of the memorial, devoid of symbolism and narrative, "grants no further understanding, since understanding the Holocaust is impossible."[46] In other words, the Holocaust Memorial is a structure that calls exactly for the kind of disconcerting disharmony that Eisenman explored in his early house designs. According to a brief explanation provided by Eisnman:[47]

> This project manifests the instability inherent in what seems to be a system, here a rational grid, and its potential for dissolution in time. It suggests that when a supposedly rational and ordered system grows too large and out of proportion to its intended purpose, it loses touch with human reason. It then begins to reveal the innate disturbances and potential for chaos in all systems of apparent order.

The formal architectural language explored by Eisenman since the start of his career thus finds a new kind of use in the memorial. As with the Facade of Morphed Columns for the Venice Biennale, the Holocaust Memorial is a different kind of architectural place, or a heterotopia, where different architectural language can be, and needs to be, explored.

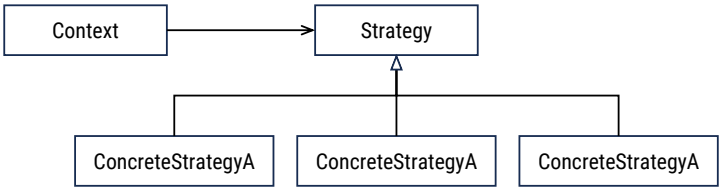


Figure 7: A class diagram illustrating the relationships between classes and interfaces in the case of the Strategy design pattern. The Context class uses a Strategy to do some work and there is a number of specific strategies that can be supplied to it.

Questioning the Structure of Software

Architects who probe formal structures of the architectural language may do so to better understand the language, uncover assumptions that we accept and rarely question and explore consequences of changing or manipulating the language. As in the previous section, this is often done using the architectural language itself. Eisenman's numbered series of houses, Gehry's residences and Parc de la Villette were all planned to be built and a number of them still stand.[48] This fact, again, points at the possibility of a critical language that is not external to the subject matter, but integrated within it. That is, the use of architecture to make critical architectural points or, in the case I am interested in, the use of programming and software to make critical points about software.

In some cases, architects use other formats too. Eisenman's doctoral work was a text presenting a formal analysis of existing buildings. The deconstructivist practice can be used to probe the process of architecture, as well as other artifacts it involves. For example, Eisenman also criticises humanist ideology of architecture through the axonometric model of the House X (Figure 6), which makes "the 'normal' image appear to be an anomaly."[49] Similarly, computer scientists and programmers should include a broader range of materials in their notion of critical language of software, including formal definitions, software specifications and demonstrations. Those can, no doubt, be constructed in a similarly illuminating distorted manner as Eisenman's axonometric model.

The analytical way of looking at basic structures of the language of the subject matter is something that computer scientists are well familiar with. It has been done at multiple levels. On one level, formal models of computations such as Turing machines and the lambda calculus have been used to describe the basic structure of computation. Like the grammar that reduces architecture to relationships between basic shapes, formal models of computation reduce program execution to a minimal set of operations. That said, there is a difference between computing and architecture in that formal models of computation originate in logic and have been conceived to study computability properties, rather than originating in the analysis of existing programs.

We can interpret software design patterns as another attempt to uncover the basic structure of software. The influential Gang of Four design patterns book[50] identifies and catalogues some 24 design patterns, which appear repeatedly in past software systems. The patterns are common structures defined by relationships between classes and interfaces in an object-oriented systems and each design pattern captures one particular structure of relationships (Figure 7). Although the Gang of Four book is a collection of a larger number of patterns whereas Formal Basis of Modern Architecture is inspired by the struc-

```
static class YCombinator<T, TResult> {
  private delegate Func<T, TResult> RecursiveFunc(RecursiveFunc r);
  public static Func<Func<Func<T, TResult>, Func<T, TResult>>, Func<T, TResult>> Fix
    { get; } = f => ((RecursiveFunc)(g => f(x => g(g)(x))))(g => f(x => g(g)(x)));
}

static class Program {
  static void Main() {
    var fac = YCombinator<int, int>.Fix(f => x => x < 2 ? 1 : x * f(x - 1));
    var fib = YCombinator<int, int>.Fix(f => x => x < 2 ? x : f(x - 1) + f(x - 2));
    Console.WriteLine(fac(10));
    Console.WriteLine(fib(10));
  }
}
```

Figure 8: Program that calculates factorial and Fibonacci numbers, unnecessarily overusing the core concepts of the lambda calculus (fixed point operator) rather than relying on standard capabilities of the C# programming language.

ture of formal grammars, they are both similar in that they analyze existing systems (software or modern architecture) to identify and describe their formal underlying structure.

Linking software patterns to Eisenman's work is ironic in that Alexander and Eisenman saw their approaches as being in direct opposition,[51] but I believe drawing the connection may be revealing. Whereas Alexander focused on creating "living structures", Eisenman is looking for "formal structures". The Gang of Four design patterns are sometimes criticised for lacking this essential "living" aspect emphasized by Alexander. The notions that Alexander has been looking for are more likely to be found in the work of Richard Gabriel[52] than in the widely used Gang of Four patterns. Despite using the name and structure of Alexander's design patterns, software patterns may well be more akin to Eisenman's formal analysis.

On another level, there have been attempts to analyze and describe how software systems are made of high-level concepts, which are rooted in the specific domain that the systems are designed for. In a book titled "The Essence of Soware",[53] Daniel Jackson views software as collection of interacting concepts. As an example, concepts involved in a social media platform like Facebook include that of a post, comment, like and a friend. The exact structure and interactions between such concepts then determines how the system behaves, how it can be used and also its social implications.[54]

All of those formal structures in software—models of computation, design patterns and concepts—can be used as analytical tools for understanding and analysing existing software as well as help programmers in creating new things. You can use models of computations as a basis for a new language, patterns to design an extensible software system or concepts to create an intelligible application.

An important lesson that post-modern architecture teaches us is that we can use such formal structures in another way. We can use them to reveal the insufficiencies of our established practices, question hidden assumptions and reveal the contradictions often present in software desing and development. To paraphrase Eisenman,[55] (admit and) show that everything is not all right. The discussion in the previous section, alongside with the illustrations shown in Figure 5, suggest some ways in which this can be done. We can use formal structures in a more or less distorted way, follow a methodology in an excessively rigorous way, or start with an atypical arrangement of the basic structures.

I doubt there are many designers of programming languages who have studied work of post-modern and deconstructivist architects and then decided to design a programming language according to the same principles. But looking at some existing programming languages, we can imagine what this might look like. If we decide to use the lambda calculus as our primary model of computation, there are multiple ways in which this formal structure can be turned into a programming language. Taking the core structures of the formal model (variables, lambda functions and application) and building a programming language around them involves bridging a large gap. A realistic programming language will need much more than the three basic primitives. Languages like Haskell resolve any design concerns that arise from this gap using a reasonable programmer's intuition—they aim at building a practically usable system.

It is equally possible to use the same formal model of computation and highlight the gap—what remains to be added in order to design a practically usable programming language is by no means obvious. One illustration of this is the esoteric programming language Unlambda[56] created by David Madore. The language is based on a combinatory logic that is related to the lambda calculus and expresses computation in terms of three primitive combinators written as S, K and I. Unlambda turns the formal model into a programming language that makes it possible to write and execute programs, such as the following Fibonacci number calculator:[57]

```
```s``s``sii`ki
  `k.*``s``s`ks
 ``s`k`s`ks``s``s`ks``s`k`s`kr``s`k`sikk
  `k``s`ksk
```

Unlambda supports a number of further functional programming concepts including continuations and lazy evaluation, and the `.*` construct prints the `*` character and returns it. Unlambda makes no attempt to be practically useful. As noted by the author "[w]riting Unlambda programs isn't really as hard as it might seem; however, reading Unlambda programs is practically impossible."[58] Unlambda is an ironical demonstration that brings to light a fact that is not otherwise easy to see. Contrasting Haskell and Unlambda shows how little of the design of the Haskell language is really determined by its core formal computational model—an interesting lesson about programming language design!

Last, but not least, we can also explore the case of integrating primitive structures from multiple formal models of computation. For example, many contemporary programming languages that are based on different principles (such as imperative, object-oriented languages) now support the key concept from the lambda calculus, that is a lambda function. (Incidentally, this replaces the Strategy design pattern illustrated in Figure 7.) Such combination of different formal structures poses a problem both for the language designers and the language users. The designers have to resolve the contradictions that arise from the integration of different formal structures. The complexity of the capture clause in C++ lambdas would be one example of this difficulty.[59] At the same time, the users of the language now have to carefuly choose between the multiple available formal structures. To point out that this is not alway easy, we can use an ironical example such as the two recursive computations shown in Figure 8.[60] A bit like Gehry's residential projects, the example "smashes" together parts of the programming language, making an aesthetic virtue of "rough, crumbled" lines of code. In both architecture and software, this distortion of the simple structure is also associated with higher maintenance costs.[61]
```

Figure 9: Stata Center designed by Frank Gehry for the MIT.

One caveat in my comparison between architecture and structures that appear in programming is that source code and programming languages typically remain hidden from sight. In contrast, the distorted formal structurs of post-modern architects are visible to their inhabitants. In case of public buildings, the structures can send a message about the institution it hosts. For example, the appearance of the MIT Stata Center (Figure 9) "is a metaphor for the freedom, daring, and creativity of the research that's supposed to occur inside it."[62] A less charitable reading of the building would be that it is a defensible use of the desires associated with the Late Capitalism to "make it an interesting test of constructional capability."[63] Either way, the visibility of the structure justifies its existence and its greater maintenance costs.

Here, the analogy between software and deconstructivist architecture raises another interesting question. Should the inner structures of programs remain hidden from their users, or should we strive to make the inner structures visible and comprehensible? Like architecture, software design is often the result of contradictory forces that arise from the user needs, physical or virtual environment and financial interests. An inner structure reflects those forces and, if it was transparent to the user or inhabitant of software, they would gain greater understanding of the software. (Perhaps, it would not take a massive security vulnerability like the 2014 Heartbleed bug to see that the core infrastructure of modern internet is critically underfunded.)[64] The fact that greater transparency would then, incidentally, also allow software designers to speak through the structure of their software would be an additional benefit of the greater transparency. I will return to this topic and how such transparency could be achieved later in this chapter.

High-level concepts, such as those identified by Daniel Jackson can be more visible and understandable to software users, so they have a greater potential as devices for communication. Seeing the concepts behind software still systems requires careful attention. As Jackson points out, "to learn about concepts, we need to see what happens when they go wrong."[65] Similarly, the structures behind architecture become visible when they are intentionally or accidentally distorted. Some post-modern architects use this fact to their leverage—using such distortions of the architectural language to speak to their audience.

An engaging and widely relatable project that distorts familiar concepts is the User Inyerface challenge (Figure 10). The web page shows a familiarly looking user registration

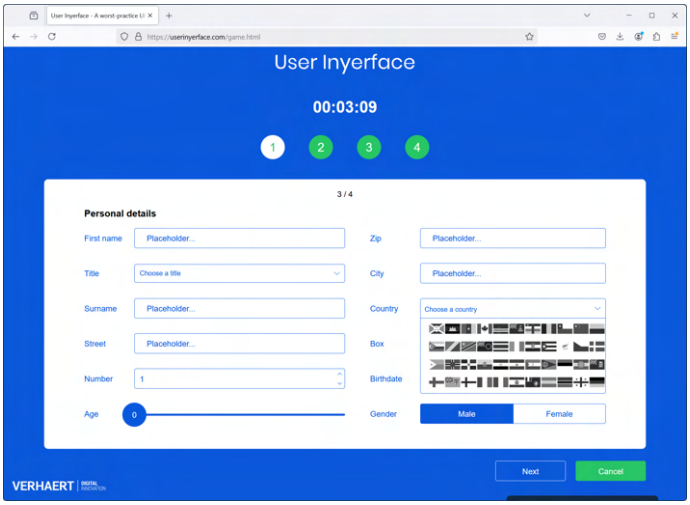


Figure 10: User Inyerface is a "worst practice UI experiment" and combines all imaginable poor practices to make correct completion of a form challenging such as counter-intuitivie highlighting of buttons, use of flags to select a country, placeholder text that has to be explicitly deleted, duplication of information (age and date of birth, or inconvenient user interface elements (age slider).

form, but it employs all possible poor design practices to make the completion of the form as hard as possible. The web page is composed from standard underlying concepts, but each of those concepts is mapped to a user element that is unsuitable in some way. In some ways, the example is similar to the case of the esoteric programming language Unlambda that I discussed earlier. Like Unlambda, the User Inyerface web page is based on reasonable underlying structures (combinatory logic or concepts of a registration form), but it shows that turning the reasonable underlying structure into an actual programming language or an interface requires resolving a number of remaining design problems.

A variety of interesting buildings and software systems emerge from the need or desire to combine multiple structures in a single resulting form. One example was the plan for the garden in Parc de la Villete by Eisenman and Derrida which overlaid a number of different structures on the single site. Similarly, I discussed how some conterporary programming

Figure 11: Hotel Fouquet designed by Edouard François, located in Paris near the Champs Elysées.

languages combine multiple models of computation earlier in this section, as well as how the interaction between those leads to contradictions. We can see the same pattern with high-level concepts of software.

Before talking about software, I want to look at one more architectural example. The Hotel Fouquet (Figure 11) was built in a quarter of Paris with strict regulations that require architects to follow the structure of historical buildings in the area. The concrete facade mimics the style of a previous building in fine details, but the facade covers a building with a different internal structure. The internal structure is visible through the windows and doors that stand out from the facade. The Hotel Foquet is an eye-catching example of a building that combines two formal structures. On the outside, it follows the style of buildings of the Haussmann's 19th century renovation plan for Paris, as required by the regulations. On the inside, it is a modern hotel building with floors and rooms arranged according to an internal logic. The windows and doors are the only points of interaction between the two structures.

If we pay attention, we can see the same interaction between multiple structures in one of the first examples that Daniel Jackson uses in his conceptual analysis of software. He looks at a sample screenshot of a Facebook page and notes that "three concepts are evident: post (represented by the message and the associated image), like (represented by the emoticons at the bottom left), and comment (represented by the link on the bottom right)."[66] Looking at a screenshot is a way of uncovering concepts from the perspective of the user—the facade of the hotel. But our conceptual analysis can equally focus on the inside of the hotel. That is, the business model of Facebook, which has been described using the term surveillance capitalism.[67] As an alternative to screenshot, we can look at the claim from the litigation by human rights campaigner Tanya O'Carroll who sued Meta (owner of Facebook) to respect her GDPR "right to object" to being profiled.[68] The concepts that are evident in the claim include direct marketing material (advertisements, promoted content), personal data (user's age, gender, location, content interactions), categories (ad interests, ad topics, your topics). When browsing Facebook, we only see the front facade. The promoted posts and advertisements we see are hints of a parallel conceptual structure of the system that we can only see if we look harder. The existence of those structures and the need to look for them and expose them is another useful lesson that the world of software can take from critical post-modern architecture.

Ways of Achieving Fit

What I hope to achieve in this text is to document the ways through which architecture can convey critical understanding and see if those ways let us talk about important issues concerning software. I moved away from Christopher Alexander, for whom the main question that matters is whether building (or software) produces living structures in the world.

I think that buildings and software should also raise critical points and much of the above was exploring some of the ways in which this can be done in software. I would now like to return to the basic question of how structures achieve good fit. This is a question that Christopher Alexander studies in detail in his "Notes on the Synthesis of Form,"[69] a book based on his PhD research written before his work on design patterns. This is, incidentally, also the text that infuriated Peter Eisenman who than opposed it in his own thesis on formal analysis of architecture.

Figure 12: Seven examples that illustrate different approaches to achieving fit. (1) Vernacular farmhouse in South Bohemia built in the 19th century in the rural baroque style ("selské baroko"), (2) Church of Our Lady of Sorrows in Dobrá Voda with entrance from the side of the nave, (3) House VI by Peter Eisenman, bult 1972-75, (4) Bauhaus-inspired Isokon building in London, built 1929-32, (5) living space of the modernist Villa Tugendhat by Mies van der Rohe, 1928-30, (6) the entrance room of the Sala House built by Christopher Alexander in 1983-4, and (7) 1966 photo of the Las Vegas Strip by Denise Scott Brown from "Learning from Las Vegas".

According to Alexander, "every design problem begins with an effort to achieve fitness between two entities: the form in question and its context. The form is the solution to the problem; the context defines the problem."[70] According to Alexander, the problem is that, in anything but the most simple scenarios, "we cannot give an adequate description of the context we are dealing with."[71] The real-world is too complex and so an attempt to logically deduce the form from a description of the context is bound to fail. The different methods of achieving fit illustrated in Figure 12 approach this problem differently.

The first approach to the problem is used by vernacular architecture, that is building done locally, in traditional ways and without guidance of professional architects. We do not need to appropriate "charms of fairy-tale countries"[72] to explain this approach. Aside from the Musgum mud huts, Alexander talks about New England barns and my illustration is a typical farmhouse in the southern region of Czechia. The way good fit is achieved

in vernacular architecture is by gradual adaptation. When building a new farmhouse, the local builder follows the same style as everyone else in the region. Since the needs of most farmers are similar, this will result in an adequate solution. When the context changes, the building style evolves gradually by small adaptations. A change is tried in one farmhouse and if it is beneficial, it is then replicated by other builders. In this mode of working, little is demanded from the individual builder. "He need not himself be able to invent forms at all. (...) All that is required is that he should recognize misfits and respond to them by making minor changes."[73] Even if the changes are not improvements, it does not matter. They will simply not be adopted by others in subsequent buildings.

According to Alexander, the professionalization of architecture destroyed this old process. However, Alexander also admits that the degree of complexity faced by modern architects is greater than that of vernacular builders. You cannot build a skyscraper using the method that works for a farmhouse. Professional architects thus approach the problem by analyzing the context and inventing a form to fit. This is the modernist methodology, rooted in the maxim "forms follows function."[74] Two examples of modernist architecture that illustrate different variations on the theme above are Villa Tugendhat and Isokon Flats. Villa Tugendhat was built as a private residence, to create "a complete vision of luxurious Modernist living."[75] As such, it featured open plan living space, retractable glazed walls and a floor plan that reflects the needs of the family, including an easy access through the garage and a separate driver's appartment. In contrast to the generous space of the Villa Tugendhat, Isokon Flats were designed as "minimal flats,"[76] inspired by the question of "how much space individuals needed to live in comfortably."[77] The flats were built for young professional men and women and provided a range of domestic services and meals made in a central kitchen. The two buildings are daring examples of radical new design that reflects the changing context. Both of the buildings invent a new form that and aims to achieve fit by analyzing the context and by emplying technical innovations.

Christopher Alexander developed a range of different approaches to the problem of achieving fit throughout his career. In "Notes on the Synthesis of Form", he suggests that "we should see the process of achieving good fit (...) as a negative process of neutralizing the incongruities, or irritants, or forces, which cause misfit"[78] and he describes an analytical incremental approach that identifies sub-problems (clusters of interlinked concerns) and gradually resolves those. His later work describes the problem as the search for what he calls "quality without a name", which happens when an environment is free of contradictions. In the writing on design patterns, Alexander and his collaborators replace the unwritten knowledge of vernacular architecture with an explicit pattern language. A good pattern language can then be used to design living structures:[79]

> Each living pattern resolves some system of forces, or allows them to resolve themselves. Each pattern creates an organization which maintains that portion of the world in balance. (...) And finally the quality without a name appears (...) when an entire system of patterns, interdependent at many levels, is all stable and alive.

The Sala house designed by Alexander shown in Figure 12 employs numerous patterns to achieve the quality without a name. Sleeping is organized in alcoves (involving patterns such as Bed Cluster, Alcove, Marriage Bed), the house relies on natural light (Tapestry of Light and Dark, Sunny Place), and the inside of the house is in relationship with the outside garden (Connection to the Earth). The process relies on an extensive pattern language,

which Alexander painstakingly developed with his co-authors over multiple years. The pattern language is supposed to capture the shared understanding of the community, which makes it possible to construct agreeable environment. Alexander's pattern language, however, leads to a particular style of buildings and Alexander himself later asked whether patterns are enough to generate the living structures he desires. Moreover, the buildings built using his pattern language are pleasant in a specific way and it is not clear whether the same approach can be used to construct other types of pleasant buildings.[80]

Christopher Alexander is not the only one who believes that the modernist rational approach to achieving fit is bound to fail. Robert Venturi, sometimes referred to as one of the founding fathers of post-modernism,[81] wrote in his 1966 book "Complexity and Contradiction in Architecutre" that Mies van der Rohe "makes wonderful buildings only because he ignores many aspects of a building. If he solved more problems, his buildings would be far less potent."[82] Venturi also cites Alexander to highlight that problems faced by architects "increase in quantity, complexity and they also change faster than before."[83] But rather than trying to resolve the resulting contradictions, Venturi welcomes them:[84]

> I like complexity and contradiction in architecture. I do not like the incoherence or arbitrariness of incompetent architecture nor the precious intricacies of picturesqueness of expressionism. Instead, I speak of a complex and contradictory architecture based on the richness and ambiguity of modern experience, including that experience which is inherent in art.

In his "Complexity and Contradiction in Architecture," Venturi documents a large number of examples of architecture that accommodates complexity and contradiction using both historical examples and his own projects. The church in Dobrá Voda, shown above, illustrates Venturi's point that the complexity of a site supports richness lacking in purer compositions.[85] The church is built in a village on a hill with a steep slope. Reflecting the site, the Baroque entrance is from the side of the nave and is visible from the open countryside that it faces—becoming an appealing landmark.

I talk about Venturi in a section focused on achieving fit mainly because of his later work, "Learning from Las Vegas"[86] written with Denise Scott Brown and Steven Izenour. The book is a study of the commercial strip, "important to architects and urbanists today as were the studies of medieval Europe and ancient Rome and Greece to earlier generations."[87] For Venturi and his collaborators, the analysis "is a socially desirable activity to the extent that it teaches us architects to be more understanding and less authoritarian."[88]

Venturi, Scott Brown and Izenour point out that architects have typically been trying to change the existing environment rather than enhancing what is already there. The way of achieving fit with the new complex environment is thus to first understand the existing environment and its language—and then build with accordance to the language. In the case of the commercial strip, documented in the book, the language is primarily a language of signs, billboards, arrows and visual symbols. The "obvious visual order of the street" is in contrast with the "difficult visual order of buildings and signs."[89] This multi-layered formal structure is not unlike that of the Hotel Foquet discussed in the previous section.

The authors use the lessons learned as a justification for their own approach to architecture, which they call the decorated shed. According to this perspective, the architectural form of the building does not matter that much. A decorated shed is designed and built as a conventional shelter, reflecting "proprietor's budget."[90] An additional content

is added to the building in the form of signs—either as literal signs in the case of Las Vegas strip or as explicit decorations in case of more ordinary buildings. The fact that the authors look specifically at the commercial strip (and the Levittown suburb in their follow-up work) for inspiration reflects their acknowledgement of existing American culture—a position that is shared with the pop art movement. Venturi, Scott Brown and Izenour can thus be seen as assuming "the role of servant to society" whose task "is to understand and interpret the wishes of the client."[91] This is in contrast to the modernist tendency "to elevant client's value system and/or budget by reference to Art and Metaphysics."[92]

The view of Venturi, Scott Brown and Izenour that architecture is "embedded in a global ideology from which there is no escape" is also a negation of the perspective of Peter Eisenman and a group referred to as "the New York Five" who see "architecture as an autonomous discourse."[93] This school of architecture offers yet another perspective on the problem of achieving fit. As I discussed earlier, Eisenman is interested in developing architectural forms as formal structures, rooted in a formal architectural language and without direct reference to humanist ideals. His architecture is "true to its own logic."[94] The problem of achieving fit is no longer a driving factor behind architecture, but something that can emerge as its effect.[95] How less likely this is when compared to other approaches likely depends on the degree to which the complexity of the problem of achieving fit, which other architects explicitly try to address, is tractable.

The idea that structures emerging from formal manipulation will find their use is not exclusive to the proponents of autonomous architecture like Eisenman. The architectural style known as contextualism also disregards functionalist rationales and instead recognizes and replicates elements from the local environment. For "if Americans won't promenade in urban plazas perhaps they will ice skate in them."[96]

Vernacular Software

The essential characteristics of vernacular architecture is that it is produced in traditional ways, without professional architects and that it achieves fit through gradual adaptation. It typically only needs to address problems of limited complexity. Vernacular architecture also develops over long periods of time, so its relevance to the world of software is not immediately apparent. Yet, there are some connections worth exploring.

The web of the 1990s had many of the characteristics of the vernacular architecture and this fact has been documented in articles and talks by the internet artist and theorist Olia Lialina.[97] In her article "A Vernacular Web", Lialina describes the web of the mid-1990s as "bright, rich, personal, slow and under construction", but also documents its vernacular nature and its demise:[98]

> One could say it was the web of the indigenous… or the barbarians. In any case, it was a web of amateurs soon to bewashed away by dot.com ambitions, professional authoring tools and guidelines designed by usability experts.

The web pages of the mid-1990s were often hosted on the free web hosting service GeoCities, which offered a simple template-driven web generator or an advanced editor for users familiar with HTML. Pages were organized in neighborhoods that grouped content by topic, but also simplified discovery of other content.[99] Although the web pages had widely varying content and graphics, many of them shared a particular style (Figure 13).

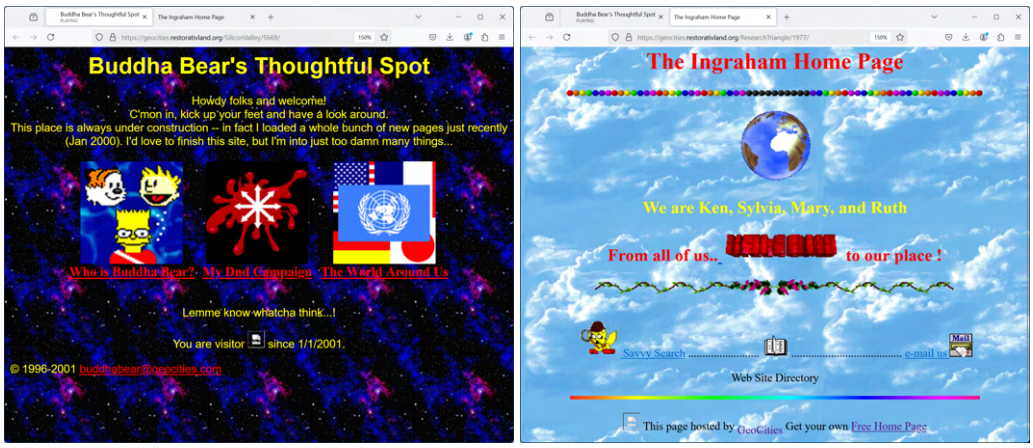


Figure 13: Two examples of typical web pages hosted on GeoCities (viewed using a modern web browser in an archive maintained by restorativland).

They were also often created using the typical methods of vernacular architecture—by copying existing structures. In particular, the modular nature of the web meant that "every line, figure, button and sound was on its own and could easily be extracted, if not directly from the browser then from looking at the source code to find the URLs of the files."[100] The reusable components of the 1990s web, such as backgrounds, buttons, music and dividers were available from collections maintained by other users.

Another area where we can find aspects of vernacular way of working is programming, as practiced by the members of the hacker community at the MIT in the 1960s. The hacker community emerged around the first available interactive computers, TX-0 and PDP-1. It embraced ideas of openness and sharing as well as individual ingenuity and skill.[101] Hackers did not learn programming through formal education, but through practice and by working with other members of the community. The hacker culture differs from vernacular architecture in that the problems solved by hackers were often very challenging and required great individual ingenuity. The ways and the tools through which they solved the particular programming problems were shared by the community and improved by a process of gradual adaptation.[102] There is also a similarity between the largely unwritten community knowledge of hackers[103] and the unwritten community knowledge of vernacular builders. The way of working personified by the 1960s MIT hackers keeps finding its use in various areas of computer programming to this day.[104] However, as a dominant way of building software, the methods of early computer hackers were replaced with an orderly software engineering method.[105]

Both of the above examples share interesting characteristics with vernacular architecture. They rely on unwritten knowledge shared by a community and also on some notion of copying and reuse. Whereas in vernacular architecture, it is necessary to copy a form when constructing new buildings, vernacular web creators relied on literal copying of code, graphics and other media elements. The fate of those vernacular computing practices also followed the fate of vernacular architecture. As observed by Alexander, "with the invention of a teachable discipline called 'architecture,' the old process of making form was adulterated and its chances of success destroyed."[106] The new "teachable disciplines" that led to the end of the vernacular web and vernacular hacker programming were professional web design or user experience design and the discipline of software engineering, respectively.

Figure 14: The Spacewar! game, created by the MIT hackers, running on a restored PDP-1 computer in the Computer History Museum

Both of those replace the unwritten knowledge and the practice of copying and learning from the community with the analysis of the context and (re)invention of new forms to fit the context. It is also the case that, like modern architecture, both modern user experience design and software engineering face problems of a greater scale and complexity.

When Bernard Rudofsky organized the exhibition "Architecture Without Architects" that popularized the term "vernacular architecture" in 1966, he was one of the first to recognize that our attitude to traditional architecture "is plainly condescending" and that:[107]

> There is much to learn from architecture before it became an expert's art. The untutored builders in space and time (...) demonstrate an admirable talent for fitting their buildings into the natural surroundings.

Architects and designers have, since then, learned to recognize the value of vernacular and indigenous architecture.[108] I believe that computer scientists and programmers should similarly look to their vernacular past for interesting ideas.[109]

The vernacular web culture is perhaps closer to the pop signs of the commercial vernacular of Las Vegas than to rural vernacular praised by Alexander. In any case, it developed into a unique creative culture and the GeoCities service itself hosted over 38 million pages by the time it was shut down in 2009, most of which were created by enthusiasts and non-professionals. How exactly this was achieved would be a subject of a fascinating socio-technical study of the era, but there are some easily identifiable technical factors that enabled this. First, the GeoCities template-based web page generator made it easy for users to get started, but it did not restrict them. There was a natural transition from a novice user to someone who can fiddle with the HTML source code, modify it and, through this process, gradually learn more about the technology. Second, the modularity of the early web made it easy to copy and reuse aspects of other sites. This included graphics and media, but also parts of the HTML markup and, later, JavaScript code that was often used to implement "pop" visual effects such as rollover (changing an image when a mouse cursor is over it) or mouse followers (element that follows the mouse cursor).

Figure 15: Replica of the Mies van der Rohe pavilion, rebuilt in 1986 after the 1929 orginal.

The technical characteristics that enabled the vernacular web could well be built into new programming systems. The first requirement is that there should be gradual progression from an end-user to a novice and, eventually, to an expert. This requires transparency. When a simple user-friendly tool guides you through the creation of new content, you still need to be able to see (and interactively engage with) the underlying representation, or source code, of the result. The same transparency is necessary for sharing of knowledge in the community. When a user finds some component or behavior interesting, they need to be able to locate its implementation, copy it (easily extracting only the relevant parts) and reuse it. The domain where this is perhaps most needed is educational software. And systems such as Scratch let you explore the gallery of other users' creations, see inside them and "remix" them (although extracting and copying components is still challenging).

The programmers of the 1960s MIT hacker culture illustrate another characteristic of vernacular architecture mentioned above—an adminarable talent for fitting their software into their technical environment. An example that illustrates this is the Spacewar! game (Figure 15) that was built to showcase the technical capabilities of the PDP-1 computer. The initial version of the game featured two spaceships with thrust, shooting torpedos at each other. Additional ideas proved challenging to implement. Adding gravity and realistic star map required inventing clever programming tricks such as compiling a special-purpose program at the start of the game to rotate the spaceship.[110]

Aside from illustrating a unique degree of fit achieved by the vernacular programming practices of the hackers, the Spacewar! example lets me illustrate another interesting parallel with architecture. In architecture, some of the most radical ideas appear in structures that are not regular buildings. This includes monumnets and follies, exhibition pavilions or stage sets. The ironic column in the 1980 Venice Bienale was one example I mentioned earlier. Another is the German pavilion built by Mies van der Rohe for the 1929 International Exposition in Barcelona, which exhibited the open floor plan and column-supported roof that we saw just six years later in the Villa Tugendhat.[111] In the world of software, demonstrations are one kind of software that plays a similar role. The special context of software demonstrations makes it possible to use them for playful purposes or to illustrate specific technical abilities—such as running an interactive game with gravity and realistic star map on a 730kg computer with a total memory of 4,000 of 18-bit words.

It may be interesting to use the lens of vernacular architecture to look at the development of programming languages too. As documented by Leo Meyerovich and Ariel Rabkin, "the original designers of today's popular languages are typically not experienced in programming language design."[112] This alone does not make them vernacular, but the languages are often created in the software equivalent of "the most complicated configurations in the landscape."[113] In words of Meyerovich and Rabkin, "a common pattern is for programmers with expertise in other domains to create a language when they perceive an unmet need."[114] Programming languages not designed by programming language designers often achieve their fit by solving a more specific problem that is initially perceived as simple. They can even be well-optimized for the initial specific problem. What they lack, or exhibit only in a limited form, is the gradual adaptation. In case of programming languages, this is typically prevented by the fact that once a language gains some users, it becomes impossible to change it.

Perhaps if each software project had to start by creating its own programming language—just like each farmer needs to build a barn—we would eventually get a vernacular programming language, highly optimized for its environment!

Modernism of Conceptual Coherence

It would be simplistic to reduce modernist architecture to the problem of achieving fit. As we saw above, modernist architects were interested in finding and supporting new modern ways of living. But this often came together with the need to find new architectural forms.

The way of thinking about software that comes the closest to modernist architecture is the notion of conceptual integrity, developed by Fred Brooks in his influential book "The Mythical Man-Month".[115] As with modernist architecture, conceptual integrity is not merely about achieving good fit or developing a system according to its specification. It is also about internal logic and clarity of the involved structures:

> Every part must reflect the same philosophies and the same balancing of desiderata. Every part must even use the same techniques in syntax and analogous notions in semantics. Ease of use, then, dictates unity of design, conceptual integrity.[116]

Even though Brooks talks about internal consistency of the design, the motivating factor is function. It is not—as with architects exploring formal grammars—internal consistency of formal structures detachd from the reality. But for "a given level of function, (...) that system is best in which one can specify things with the most simplicity and straightforwardness."[117] In software, the problem of achieving internal consistency is as tricky as the problem of achieving fit between the form and the context in architecture. Brooks believed that it is possible to achieve conceptual integrity if the design proceeds "from one mind, or from a very small number of agreeing resonant minds."[118]

Interestingly, the modernist methodology in the world of software also partly responded to the newly emerging "modern" ways of using software. The Mythical Man-Month was published in 1975. It reflected the author's experience of working on the operating system for the new IBM/360 line of computers. However, it also appeared a couple of years after other two major developments in the software industry. One was the 1968 NATO conference on Software Engineering that introduced the very term "software engineering" and

is sometimes seen as marking the move from the "black art of programming" to the new science of "software engineering".[119]

Another development was related more to the way computers were employed by businesses. The influential McKinsey report "Unlocking the Computer's Profit Potential"[120] published in 1968 argued that many "large companies have successfully mechanized the bulk of their routine clerical and accounting procedures" using computers. According to the report, most companies were only slowly realizing that the "second stage of the computer revolution, unlike the first, entails real operational changes."[121] In other words, the managers responsible for the use of computers need to move from simple automation of existing processes to finding new ways of utilizing computers in their companies. I would argue that there is a similar interplay in this development as in the modernist architecture. Just like modernist architecture reflected and enabled new modern way of living, new modernist approach to software development has been interconnected with new modern ways of using computers from the 1970s onward.

The software development methodologies of the 1970s are now perhaps more obviously outdated than the modernist architecture of the 1930s. What followed them—and to what extent can the different alternatives be related to various post-modern tendencies in architecture—would be an interesting question to explore further. There may be some interesting analogies. I will look at ideas inspired by formalism of Eisenman and post-modernism of Venturi later. Concerning development methodologies specifically, many of the later developments learned to better acknowledge the "complexity and contradiction" involved in the typical sofware project. Distributed open-source development methodologies characterized by Raymond in "The Cathedral and the Bazaar"[122] emerge from complex social structures, but are at least as effective as Brooks' "one mind"; the Agile development methods aim to achieve fit by gradual adaptation and would be closer to vernacular methods praised by Alexander.

Critics of modernist architecture and modernist urban planning pointed out a number of its limitations. Many of those are also relevant for software. One of them has been pointed out by French architect and theoreticiaan Bernard Tschumi:

> While the puritanism of the Modern Movememnt and its followers has often been pointed out, its refusal to recognize the passing of time has rarely been noticed. (Not surprisingly, glass and glazed tiles have been among the preferred materials of the movement—for they do not reveal the traces of time).[123]

Software systems do not decay in the same literal way as the materials used in buildings (there is no plaster falling off the concrete blocks of the software equivalent of the Villa Savoye as discussed in Tschumi's article). The kind of decay that software faces is more often caused by changes in its environment, that is the context that initially shaped the form. In the world of software, the requirements change as the situation in the real world that the software responds to changes, the technical platforms and systems on which software runs change, programming languages and styles evolve and components the software is built from change (npm packages being the most notorious example).

Modernist software is not built to adapt well, just like most modernist buildings are not built to adapt well. Modernist architecture "made the profound mistake of taking a snapshot of the high-rate-of-change 'organic life' within building and immobilizing it in a (…) low-rate-of-change structure and skin of the building."[124] Or as Stewart Brand puts it "The credo 'form follows function' was a beautiful lie. Form froze function."[125] The

Figure 16: The demolition of the second Pruitt–Igoe building, April 21, 1972.

possibility of designing more adaptable building, as well as more adaptable software, is an interesting problem that I will return to later. (In particular, I want to see if there could be a software equivalent of Brand's "material that looks bad before it goes bad," i.e., a way of building software where the material warns us about likely imminent structural faults.)

Whereas the failures of modernist architecture were typically limited to individual buildings, the failures of modernist urban planning—rooted in the same principles of rational planning—were more high-profile. An iconic example has been a large housing project, built as part of urban renewal projects, often to replace former slums. The demolition of one such housing project, Pruitt-Igoe in St Louis, in 1972 has been labelled as the day modern architecture died by architectural critic Charles Jencks (Figure 16). We can see the housing projects as monumental scale follow-ups to the modernist Isokon building that I examined earlier—and the monumental scale, as well as very different socio-economic conditions, is likely why their fate was different.

The foremost critic to oppose the modernist urban planning was Jane Jacobs. In her 1961 book, "The Death and Life of Great American Cities,"[126] Jacobs looked closely at the street life in Greenwich Village and Boston's North End neighborhood at the time and documents what makes them work. This includes lively mixed-use, dense population and "eyes on the street", as well as diversity of buildings and diverse population. That is, properties that were mostly absent in modernist housing projects. Jacobs' analysis raises a number of questions about software, some of which I explored elsewhere such as:[127] If the rational structure does not produce working software, what are the characteristics of software and programming systems that actually do it?

One interesting inquiry into the modernist urban planning came James C. Scott who identifies modernist patterns—similar to those of modernist urban planning—in a range of other areas of society including forestry, agriculture and politics. However, many of the modernist structures that Scott talks about find some way of working. In Scott's account, this is often enabled by "dark twins", that is inofficial structures that exist hidden from the official modernist view that arise "to perform many of the various needs that the planned

```typescript
// Recursively retrieves a nested value from an object using a path
function getValueByPath(obj: any, path: string[]): any {
  if (path.length === 0) return obj;
  if (typeof obj !== "object" || obj === null) return undefined;
  const [key, ...restPath] = path;
  return getValueByPath(obj[key], restPath);
}

// JSON data could come from external source
const sample = '{ "user": {
  "name": "Bup",
  "address": { "city": "Prague", "zip": "17000" }
}}';
const parsed = JSON.parse(sample);

// Access nested object members dynamically
getValueByPath(parsed, ["user", "name"]);
getValueByPath(parsed, ["user", "address", "zip"]);
```

Figure 17: A TypeScript example using the `any` type to dynamically process JSON input.

institution fails to fulfill."[128] One personification of the concept of dark twin, documented by Scott is the East German factory worker, touring the country in his Trabant auto to secure key missing parts not available through official channels, in exchange for valued goods such as fashionable clothes or champagne, purchased using factory funds.[129] (Another example would be the illegal freelance engineer Archibald Tuttle in Terry Gilliam's movie Brazil.)

The idea of dark twins raises a question about software design as well. To parphrase Scott—to what extent is successful modernist software design parasitic on similar informal processes that it cannot create or maintain?[130]

I believe one illustration of the above is the type system of the TypeScript language. (More specifically, I will consider earlier versions of the language. In later versions, the understanding of types in TypeScript has evolved.) The type system of early TypeScript featured many types that are common in type systems of more pure languages: primitive types, object and interface types, function types, union types and generic types. Those are useful for much of "modernist" code that operates on clear and well-defined structures. But not all code is like that. All programs also need to work with some kind of external data (Figure 17) and this cannot easily be done using purely modernist type system. TypeScript solved the problem by also including a dark twin—the `any` type. The type breaks the pure modernist properties of the type system (the system cannot guarantee any safety), but its inclusion was likely crucial for the adoption of TypeScript. The system could actually be used in practice to work with data and interoperate with the JavaScript ecosystem.

The evolution of the TypeScript type system deserves a further analysis. Later versions continued adding features that reflected typical (non-modernist) coding patterns in JavaScript. As the number of dark twins in the system grew, they became integrated into the official structures of the type system—so what started as modernist design with the necessary supporting dark twins may have evolved into a post-modern assemblage.

Figure 18: Additonal floors and other additions on the top of a 19th century palazzo in Naples

Complexity and Contradiction in Software

The TypeScript story that I hinted at in the previous section may serve as an illustration of an important fact. In the earlier versions, we could read the language as being based on modernist design, featuring strong rational type system. There were some unavoidable dark twins, necessary to make the design practical, but those were only (somewhat) reluctantly admitted. However, the later versions of TypeScript seem to acknowledge and embrace the complexities and contradictions inherent in the system, which combines some aspects of initial rational design with the many complexities of the environment and perhaps also whims of the most recent JavaScript framework creators.

Should programmers and computer scientists embrace complexity and contradiction in software, in ways that are similar to those advocated by Robert Venturi for architecture? First, there is a certain honesty in acknowledging complexity and contradiction in cases where it cannot be avoided. Venturi himself also does not argue for introducing unnecessary complexity. He says that "abstruse architecture is valid when it reflects the complexities and contradictions of content and meaning."[131] Venturi praises a number of benefits of working with this fact.

The fact that contradictions support "richness" in design (as illustrated by the church in Dobrá Voda above) is perhaps primarily aesthetical and not necessarily of interest for software designers. Still, working in an atypical context may serve as a source of inspiration for novel design. For example, many of the interesting aspects of the Erlang programming langauge arise from the fact that it was initially designed for telephony applications, which are highly concurrent, distributed and must be fault tolerant, supporting change "on the fly" without a loss of service during update.[132]

Another interesting observation about complexity made by Venturi is that complexity is robust. It provides an answer to the criticism of modern design that I mentioned in the previous section. Whereas "one foreign element casts into doubt the entire effect of some modern buildings,"[133] a "good deal of clutter" and renovations does not destroy

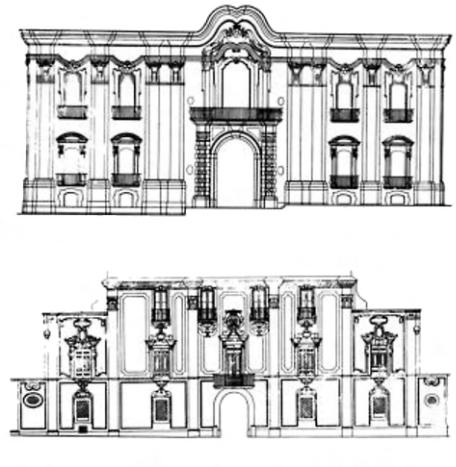


Figure 19: Two villas used to illustrate how contradiction can be manifested. Contradiction is adapted in Villa Pignatelli (above), and juxtaposed in Villa Palomba (below).

the Italian urban scene of many times adapted and reconstructed palazzi (Figure 18). This seems to be the case about programming languages too. Consider the C++ language as an example. "C++ is complicated, too complicated."[134] It also has many "complicating legacy features."[135] Yet, none of those have destroyed the coherence of the language. The language embraces the complexity:

> Today, some of the most powerful design techniques combine aspects of traditional object-oriented programming, aspects of generic programming, aspects of functional programming, and some traditional imperative techniques. Such combinations, rather than theoretical purity, are the ideal.[136]

Although the language designers still strive for coherence, they also acknowledge that a design "by a 350+ member committee is unlikely to produce a coherent result." But given the complexity of the ecosystem, there is no way of avoiding this. A "mature language needs dozens or even hundreds of people working on the huge variety of problems that must be faced."[137] I believe that the design of C++ has been embracing complexity and contradiction, perhaps for longer than the designers would admit. But this has made the langauge robust to additions and extensions that were needed to keep it "thriving in a crowded and changing world."[138]

Venturi also identifies two ways in which contradictions can be manifested (Figure 19). In case of adapted contradiction, the design finds some compromise between the two contradicting factors, such as by adapting the window mouldings. In case of juxtaposed contradiction, there are no compromises and, for example, windows appear where the inner layout needs them. The Hotel Foquet (Figure 11) was an extreme case of this approach. Venturi contrasts the two options as follows:

> Contradiction adapted is tolerant and pliable. It admits improvisation. It involves the disintegration of a prototype—and it ends in approximation and qualification. On the other hand, contradiction juxtaposed is unbending. It contains violent contrasts and uncompromising oppositions. Contradiction adapted ends in a whole which is perhaps impure. Contradiction juxtaposed ends in a whole which is perhaps unresolved.

I believe that we can, again, find examples of both approaches in the domain of programming language design. Take, for example, the problem of integrating functional pro-

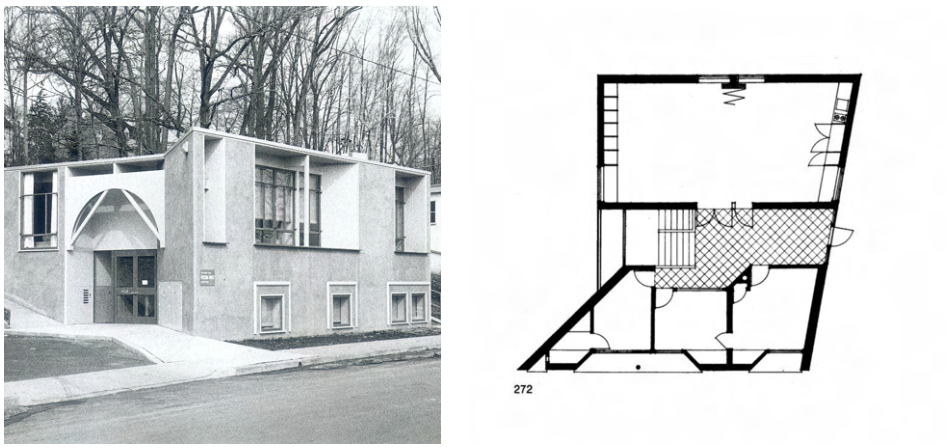


Figure 20: Headquarters Building, North Penn Visiting Nurse Association, Venturi and SHort, 1960.

gramming languages with the support for side-effects such as performing IO operations. On the one hand, in languages like OCaml and F#, the contradiction is adapted. Side-effects are tolerated as part of normal functional programs at a certain cost—such as the impossibility of making such language lazy. On the other hand, in languages that rely on monads like Haskell, the contradiction is juxtaposed. Effectful computations are explicit and their integration is unbending. And whereas the OCaml and F# design is impure, the Haskell design is unresolved.

Another interesting aspect of acknowledging and working with complexity is that it can aid transparency. This can be illustrated using one of Venturi's own projects, documented in the Complexity and Contradiction book (Figure 20). The contradiction that the design resolves is between the "complex inside (…) with varieties of spaces and special storage accommodations" and "bold scale and simple form" of the outside of the building. A trace of the resolution of the contradiction can be seen in the visible form of the building:

> As for the program complexities of the interior, a hint of the storage intricacies is confirmed in the alternating recessions of windows and closets in the front.[139]

In other words, if we look at the building front (and perhaps know what we are looking for), we can see traces of the interior storage spaces in the facade. The building is not trying to hide the fact behind a simple uniform facade. There is, perhaps, a degree of honesty in the design, but it also allows us to understand the building and its function better.

I believe that embracing a design which leaves a trace of complexities it resolves is an interesting option for software and programming systems. As software designers, we are often using abstractions to hide the internals of a system from its users (or other developers). But such abstractions often hide contradictions that the implementors had to resolve in some, often imperfect way. If the abstractions do not leave any hint of such complexities, it is easy to hit their limitations and use them in a way in which they break. Being able to see through the abstractions—even if through limited hints—may thus be of a practical value.[140] How exactly to achieve this, I leave as an open question for now.

```
(* Define abstract signature of a module
   and provide concrete implementation *)
module type MySig = sig
  type t = int
  val x: int
end
module MyModule: MySig = struct
  type t = int
  let x = 10
end
```

```
/* Define abstract signature of a module
   and provide concrete implementation */
module type MySig = {
  type t = int;
  let x: int;
};
module MyModule: MySig = {
  type t = int;
  let x = 10;
};
```

Figure 21: An example from a comparison between OCaml and Reason ML showing the new syntax.

Learning from Software Pop Culture

Venturi's rejection of modernism was based on finding richnes resulting from the complexity and contradiction in a wide range of historical and vernacular examples of buildings. Learning from Las Vegas extends the critique, arguing that architects should pay attention to the commercial vernacular and, generally, the way buildings resulting from the contemporary pop culture are structured. The architectural inspiration that Venturi, Scott Brown and Izenour derive from their study is that of a decorated shed, a building with simple inner form whose meaning is defined by its use of signs. I believe we can use both of these concepts—learning from the pop culture and the notion of a decorated shed—to critically examine software and programming systems.

In programming languages and systems, the idea that a programming language can be seen as a formal mathematical entity was an major invention at the end of the 1950s. It facilitated the development of many programming languages and concepts, including the influential Algol language. The consequence of this view was that languages were often designed mainly with attention to their formal structure and internal coherence (which can be seen as a combination of modernist view that I discussed above and formalism that I return to later).

However, a number of more recent programming languages moved away from the strictly modernist or formalist designs and embraced interaction with the context in which they operate—or even learn from the commercial culture and embrace some of their pop symbols. A programming language that both conceptually and technically fits the notion of a decorated shed is Reason ML. It was released in 2016 and has been described as:

> Reason is not a new language; it's a new syntax and toolchain powered by the battle-tested language, OCaml. Reason gives OCaml a familiar syntax geared toward JavaScript programmers (...).[141]

The Reason ML provides new syntax and tooling for the existing and much older OCaml language. Despite numerous advanced aspects, OCaml can be seen as a simple and conventional underlying structure. However, to produce a language that is more appealing to the intended public—JavaScript developers—the shed is decorated with a new syntax derived from JavaScript. In particular, Reason ML uses curly brackets and JavaScript-like syntax for comments (Figure 21). Although there are some technical advantages of the syntax, the main motivation for the syntactic redecoration is familiarity.

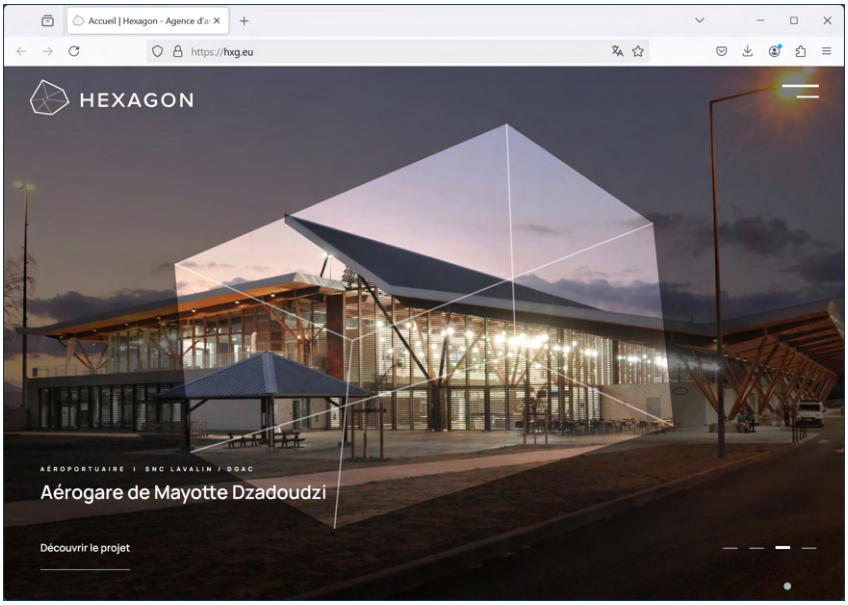


Figure 22: A highly customized WordPress web page for the Hexagon architectural firm. Their buildings may not be decorated sheds, but their web site certainly is.

The example of Reason ML shows that the architectural design principle of a decorated shed, conceived of by Venturi, Scott Brown and Izenour can be directly applied in the world of software too. As with Venturi's first buildings based on the decorated shed idea, Reason ML was received with mixed reactions. In particular, some saw it as a superficial step backward. But the example also shows how the design principle lets designers avoid the modernist reinvention of form. Rather than solving the problem of fit anew, the designers can leverage an existing adequate solution and make it more appealing for the context that it now needs to exists in.

The concept of a decorated shed can also be linked to a point made by Fred Brooks in his essay No Silver Bullet,[142] published in 1986, where he argued that:

> There is no single development, in either technology or management technique, which by itself promises even one order of magnitude improvement in productivity, in reliability, in simplicity.[143]

Brooks' argument was based on the analysis of the complexity of software design. He sees it as a combination of essential complexity, inherent in the problemm and accidental complexity arising from the imperfection of our processes and tools. Resolving the essential complexity in software design amounts to achieving fitness between the form and the context. Brooks suggest some "promising attacks" on the problem including, most prominently, "buy versus build":

> The most radical possible solution for constructing software is not to construct it at all. Every day this becomes easier, as more and more vendors offer more and better software products for a dizzying variety of applications.[144]

The development envisioned by Brooks in 1986 has happened in multiple areas. Brooks already mentioned database systems and spreadsheets. Nowadays, there is a number

of pre-existing packages ranging from e-commerce platforms and accounting software to content management systems. Many of those systems follow the design principle of a decorated shed in a very literal sense. For example, content management systems such as WordPress (Figure 22) make it possible to customize the publicly facing look of the system through themes, while the underlying structure remains the same. (Although, the structure can often also be adapted configured via plugins.) Again, the decorated shed makes it possible to use an existing adequate strucutre, but decorate it with symbols and ornaments to communicate thes desired message.

Decorated shed is an intriguing specific design principle that can clearly have implications for software and programming systems, but we can also consider the more general point of learning from existing urbanism—or software ecosystems. After all, Learning from Las Vegas was intended as "a study of method, not content."[145] How else can we learn from existing software ecosystems when designing new structures?

I will, again, use TypeScript as my example. Unlike Reason ML, TypeScript is not merely a decorated shed, but a new language with its own new complexities. As a superset of JavaScript, the language is derived from an existing structure with complex history. We could analyze this and, for example, document what kind of richnes emerges from the complexity and when the complexity is adapted or juxtaposed. (JavaScript and TypeScript mostly seem to follow a concilliatory approach resulting in adapted complexity.)

However, I want to focus on one aspect of the TypeScript type system design that can be seen as an example of learning from the pop culture. TypeScript programmers need to interoperate with a large number of JavaScript libraries. In order to provide type annotations for those libraries, the type system of TypeScript needs to be expressive enough to cover the scenarios that often appear in existing libraries. The designers thus need to analyze existing practices and libraries, many of which emerged without much concern for programming language or type system design. Figure 23 provides two examples. The first code snippet shows how TypeScript overloading made it possible to provide a typed interface for the `createElement` function, which returns a different kind of object depending on the value of the first parameter (and which predates TypeScript by some 15 years). The snippet combines string literal types (treating a string value as a type) and overloading.[146] The second snippet uses template literal types, which make it possible to construct string literal types through templates. Here, the feature is used to define type for a range of valid CSS class names that the external library, Tailwind, defines.

To what extent is it fitting to see JavaScript libraries as a commercial pop culture of Las Vegas may be open to discussion. The more important point here is the design methodology that language designers need to use if they are creating a language to fit with an existing complex and contradictory ecosystem. As noted by Venturi and his co-authors, "analysis of existing American urbanism (…) teaches us architects to be more understanding and less authoritarians in the plans we make (…)."[147] In the same way, understanding and learning from what exists in existing software ecosystems that programming languages interact with teaches programming langauge designers to be less authoritarian and and adapt (or juxtapose!) their designs with respect to this context.

The analysis of existing context and culture can be done in a number of ways and result in a range of designs. To some extent, the design of JavaScript still aims at the modernist maxim "less is more". For example, it resolves the complexity of the `createElement` typing using otherwise useful and reusable constructs (overloading and string literals) rather than

A type definition for `createElement` using overloaded function signature (TypeScript 2.0):

```
interface Document extends Node, GlobalEventHandlers,
   NodeSelector, DocumentEvent, ParentNode {

  /**
   * Creates an instance of the element for the specified tag.
   * @param tagName The name of an element.
   */
  createElement(tagName: "a"): HTMLAnchorElement;
  createElement(tagName: "applet"): HTMLAppletElement;
  createElement(tagName: "area"): HTMLAreaElement;

  /* 75 lines of code listing other overloads omitted */

  createElement(tagName: "video"): HTMLVideoElement;
  createElement(tagName: "x-ms-webview"): MSHTMLWebViewElement;
  createElement(tagName: "xmp"): HTMLPreElement;
  createElement(tagName: string): HTMLElement;

  /* 900 lines of code listing other DOM functions omitted */
}
```

A type definition for Tailwind class names using template string literals (TypeScript 4.1):

```
type Colors = "red" | "blue" | "green" | "yellow";
type Shades = "100" | "200" | "300" | "400" | "500";

type TailwindTextColor = `text-${Colors}-${Shades}`;

let validClass: TailwindTextColor = "text-red-500";
let invalidClass: TailwindTextColor = "text-purple-900";
```

Figure 23: Two definitions that use increasingly complex type system features to provide accurate TypeScript types for external JavaScript libraries.

through ad-hoc mechanism. But the complexity of the ecosystem in which it exists forces it to often adopt the post-modernist approach "less is a bore".

An even more modernist approach to learning from the preexisting context can be illustrated by various attempts to base the design of a programming language on empirical observations of programmers, or the analysis of existing code in large software repositories such as GitHub.[148] Such over-reliance on facts is the starting point for Peter Eisenman's doctoral work. Eisenman presents his objection using a reference to earlier witings of American historian Carl L. Becker:

> Becker describes the modern climate of opinion as factual rather than rational (...). For Becker, history, the question of facts and how they are related, has replaced reason and logic, the question of 'why?'[149]

In the next section, I will move from the factual approaches—be it the modernist analysis of context or post-modernist reading of contemporary culture and its symbols—to software and programming systems designs that employ rational analyses based on reason and logic.

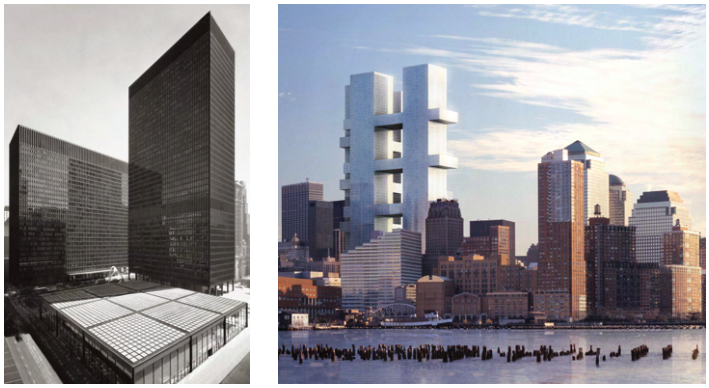


Figure 24: The Chicago Federal Center building (Mies van der Rohe, 1964) and Memorial Square World Trade Center project (Peter Eisenman, 2002).

Emergence from Formal Structures

At the first sight, the formal structures designed by Peter Eisenman seem similar to modernist architecture (Figure 24) and some of his critics saw his focus on formalism and abstraction as a return to outdated modernist ideals. As I illustrated through a number of examples earlier, Eisenman works with simple formal modernist structures, but he uses them for a different purpose than modernist architects. His project for the World Trade Center memorial, for example, turns the horizontal Manhattan grid into a vertical one, using a rational modernist structure as a formal entity.

Eisenman's approach, apparent already in The Formal Basis of Modern Architecture is to work with basic geometric structures such as the grid, mass, volumes and surfaces—and to see how they interact in order to form a building. A computer scientist reading his thesis can easily read the work as defining a domain-specific langauge for describing architectural structures. The language is formed of primitives and combinators that can be used to put the primitives together. The important point, however, is that the basic structures are geometrical and rooted in analysis of abstract architectural forms. They do not arise from analysis of function.

As discussed earlier, I believe the most direct software counterparts to basic architectural structures are formal models of computation such as the lambda calculus and Turing machines. It is also fitting that these two specific models existed in the domain of formal logic before the first digital electronic computers and programming languages. They are thus not modernist abstractions, resulting from the analysis of the function of software, but a priori structures of computation. The two models can be contrasted with formal models of parallel and concurrent systems such as Hoare's Communicating Sequential Processes (CSP) developed in the 1970s,[150] which were derived from existing programming patterns. For example, Hoare explicitly notes that his notion of a process "may constitute a synthesis of a number of familiar and new programming ideas."[151]

To keep the software examples as close to the architectural ones, we can look for formal structures that describe some aspect of computation or program structure, but are not conceived as models of existing practical programming languages. An interesting question to ask is how those structures resolve the problem of achieving fit between the form and the context. Does the fit emerge as (perhaps) an accidental effect of the use of formal

```haskell
import Control.Monad (forM_, forM)

main :: IO ()
main = do
   -- Get a number of words and then read them
   putStrLn "How many words will you enter?"
   count <- readLn
   words <- forM [1..count] $ \i -> do
      putStrLn $ "Enter word " ++ show i ++ ":"
      getLine
   -- Print the words back to the output
   putStrLn "You entered:"
   forM_ (zip [1..] words) $ \(i, word) -> do
      putStrLn $ show i ++ ". " ++ word
```

Figure 25: A Haskell program that echoes a list of words read from the user.

structures? Or does the use of autonomous formal structures result in "unlivable" buildings, as critics of Eisenman occasionally like to point out?

If we see the lambda calculus as the formal structure that underpins functional programming languages, then there are certainly many domains where the emergent form fits with a context. Functional list processing, which inspired LINQ and Java Streams, would be only one such example. This claim necessitates some caution, though. The Lisp language, often regarded as the first functional programming language was not directly based on the lambda calculus. Its author, John McCarthy "was aware of [the lambda calculus] but had not studied it."[152] The specific example of functional list processing also does not require nearly the full power (or even the key structures) of the lambda calculus.[153]

Later functional programming languages, including most notably Haskell, have the lambda calculus as a more direct predecessor. The popularity and non-negligible industrial adoption of Haskell shows that a formal structure can give rise to a well-fitting form. But again, some caution is needed. As the earlier analysis of the esoteric programming language Unlambda suggests, the good fit may not necessarily be the result of the underlying formal structure, but a result of a pragmatic resolution of the remaining design problems.

Another source of formal structures that have been used as the basis for programming abstractions, especially within functional programming, is category theory. Category theory is a branch of abstract mathematics concerned with general structures and their relations. As such, it perfectly fits the bill of being a source of generic forms that can be applied to understand and design software structures.

The most prominent categorical structure that found its use in programming is a monad. Initially used to formally model the semantics of effectful computations in a functional language, monads were later implemented in Haskell alongside with the `do` notation for working with them. The abstraction was adopted for a number of use cases, including handling of input and output, which "has always appeared to be one of the less satisfactory features of purely functional languages."[154] A quote from the paper that introduces monadic input/output recognizes the good fit that emerged from the use of the formal structure:

> This paper outlines a new approach [for input/output in lazy functional languages] based on monads (…). We do not claim any fundamental expressiveness or efficiency which is not obtainable through existing systems (…). Nevertheless we feel that the entire system works particularly smoothly as a whole, from the standpoint of both programmer and implementor.[155]

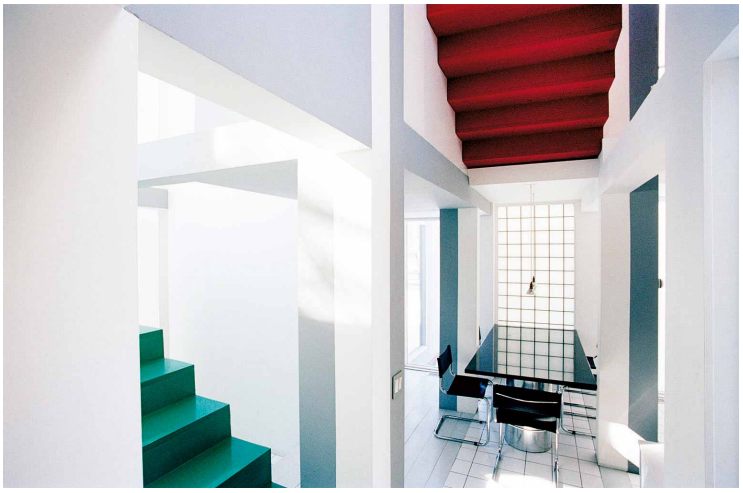


Figure 26: Eisenman's House VI (1975) is generated using a small number of formal operations.

The example shown in Figure 25 uses monads and the `do` notation to implement a simple program that reads a number of lines from the input and prints them back to the user. The example is intentionally chosen to require a number of monadic structures. It uses the `forM` function to iteratively execute function that reads input, `forM_` to print outputs (a version with underscore ignores the results), and it uses three `do` blocks to sequence imperative operations. In this particular example, the formal structure of a monad permeates the entire program. (Contrast the example with more recent approach to handling input/output effects based on algebraic effect handlers where constructs such as iteration are not affected by the effects.)

To question the design of monadic input/output, we can compare the computer program design generated through a formal structure (monads) with architecture generated through a formal structure. Consider the House VI designed by Peter Eisenman:

> House VI was in fact the result of the application of a few limited rules (displacement, rotation, compression and extension), to a restricted number of elements (volume, vertical layers and the nine square grid). All these operations produced several diagrams, whose relevance replaced the notions of materiality, function, and meaning.[156]

The consequences of the design methodology are apparent in Figure 26. Some of the beams in the house play no structural role, but are present for merely formal reasons. This includes the column hanging over a dining table. Another artifact generated by the design method is the inverted red staircase, which hints at the fact that the house may well continue to function if it was flipped upside down. Rather than achieving a fit between the form and the context, the house sends a message:

> As annoying as the house was to inhabit, Eisenman was able to constantly remind the users of the architecture around them and how it affects their lives.[157]

The use of monads for input/output in Haskell is certainly not as annoying. After all, the authors praised the system for working "particularly smoothly" when introducing the idea. However, the use of monads as a formal structure to generate library designs in

functional programming languages has also found its critics, myself included. In "What we talk about when we talk about monads"[158] I pointed out that "there are a number of cases where monads were used in an academic paper and their use was later revised or avoided." Interestingly, some of those undesirable uses of monads are not unlike the undesirable effects that the use of formal structures generates in Eisenman's House VI.

The first example is that of monadic parser combinators.[159] Parser combinators emerged as a functional and compositional way to construct parsers. When it turned out that parsers can match the structure of a monad, most implementations of parser combinators started to follow this formal structure. However, the structure implied by monads was often not practically necessary—it was the result of formal decision, rather than a decision arising from the required functionality. In contrast to parser combinators that were not based on monads, monadic parser combinators were also less efficient and had poor error reporting. In some way, monadic parser combinators are not unlike the formally appealing, but practically unnecessary columns in Eisenman's House IV.

The second example is the use of monads for capturing dataflow computations. As pointed out by Dominic Orchard,[160] computer scientists initially tried to model dataflow computations using the formal structure of a monad. Later work argued that this cannot be done and instead proposed to use a formally dual structure of a comonad. Although the desired implementation could, to some extent, fit both of the structures, it later turned out that other aspects of the model (such as how easy it is to use it in formal reasoning) are easier to achieve with the dual structure. What the example suggests is that there are unexpected properties of formal structures whose practical implications may remain ununderstood. Perhaps Eisenman's House IV would, indeed, work better if it was flipped upside-down, as eventually happened with formal models of dataflow computations?

The conclusion we can draw from these examples is the same for architecture and for computer science and programming. In the case of modernism, the problem was the difficulty of fully understanding the context. In the case of formalism, we instead opt for a design methodology taht disregards the context. Formal structures have a great appeal and many useful structures can emerge as the result of formal manipulation. But there is no guarantee that they will result in a good fit between the form and the context.

New Modes of Criticism

I opened this text with a reference to Christopher Alexander's OOPSLA 1996 keynote where he wondered if programmers and computer scientists are willing to act as "guns for hire". He continued his presentations with an invitation:

> What I am proposing here is something a little bit different from that. It is a view of programming as the natural genetic infrastructure of a living world which you/we are capable of creating, managing, making available, and which could then have the result that a living structure in our towns, houses, work places, cities, becomes an attainable thing.

In the (almost) 30 years since his presentation, software has indeed became a kind of genetic infrastructure of a living world, although not always in the most desirable ways—to use Alexander's terminology, software has not always provided us with living structures. Alexander's lifetime work has been concerned with understanding living structures and finding ways of creating them. My own interest in this text is way more modest.

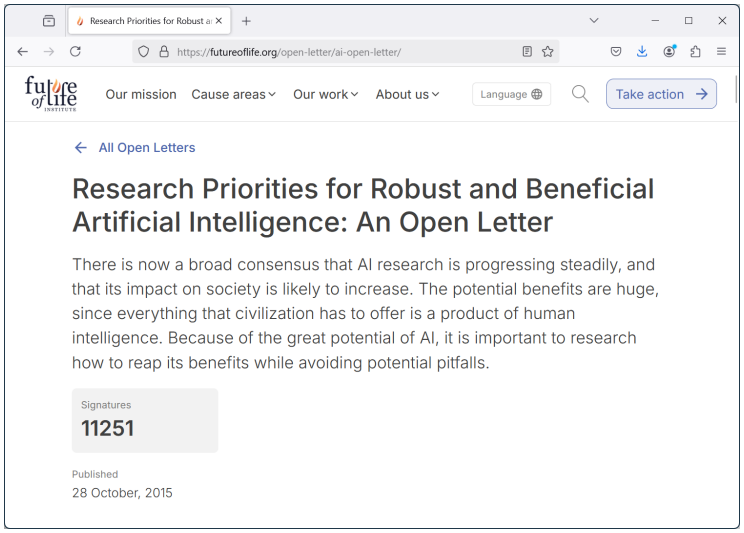


Figure 27: Research Priorities for Robust and Beneficial Artificial Intelligence: An Open Letter

I think we need a richer critical language for thinking about software. When we critically examine software today, we most frequently approach it from one of two perspectives. The first perspective is technical. Does the software work as it was intended to? Even if most software built today is not developed according to an up-front specification, the technical perspective is still concerned with its functionality. In the case of more abstract systems like programming languages, we still ask technical questions, such as how effectively they support different use cases. The second perspective is social. What is the effect that the software has on the society and individuals? In response, much has been written about algorithmic bias, exploitation of personal data or the role of social media.[161]

I believe that the two disconnected perspectives are insufficient for critical thinking about software. To put it bluntly, the technical perspective asks the wrong questions, whereas the social perspective glosses over too many crucial details. The gap is apparent if we look at the 2015 open letter "Research Priorities for Robust and Beneficial Artificial Intelligence"[162] (Figure 27). The introduction of the letter talks about the impact of AI on society and the letter lists multiple social science questions (policy, economics, ethics). The computer science priorities are highly technical problems like security, control and the classic problem of "how to prove that a system satisfies certain desired formal properties". Notably absent from the letter is a call for closer integration between the two perspectives of looking at the system. What I am interested in is finding ways of engaging with the technical structure of software, but not through technical questions.

I have been using architectural theory as an inspiration for ideas on the critical language of software—partly because of the existing connection between the disciplines, but also because of the rich literature concerned with critical reading of architecture. In 1977, Jorge Silvetti described an emerging critical discourse within architectural theory that he calls "criticism from within" and which complements existing approaches:[163]

> [The] "realm" of criticism has traditionally been divided between two opposing modes: one that tries to evaluate the degree of "fitness" or "'non-fitness" of a solution to a particular architectural question and another that attempts to see both the question and that solution as parts of a larger historical, cultural, or ideological process.

Figure 28: Vanna Venturi house (1964). Robert Venturi reintroduces elements traditionally associated with houses, but in a minimal form and stripped of their original functions.

The two opposing modes of criticism identified by Silvetti are remarkably like the two critical ways of looking at software. Post-modern architecture that emerged in the late 1960s brought with it a new critical discourse. The new "criticism from within" had a range of forms and aspects, many of which were discussed in detail by Silvetti in 1977. Those include the idea of treating architecture as a language that can be subjected to analysis and manipulation. Inspired by Chomsky, we can study the syntax of the language; inspired by French structuralists, we can study the systems of signs employed by the architectural language. Using figures of classical rhetoric, Silvetti gives examples of buildings that "all operate with known architectural codes, and they all redeploy these codes by effecting some easily perceivable changes."[164] The changes introduce figures such as hyperboles, paradoxes, ironies and ellipses (Figure 28).

Silvetti analyses the new "criticism from within" in terms of a metalanguage that is used to talk about the language of architecture. A text that comments on a building would be an example of such metalanguage. What the new "criticism from within" brought is "the very special case of metalanguage in which both discourses belong to the same practice; architecture commenting on architecture, architecture 'speaking' of itself."[165] This is the idea that I developed in the first two parts of this text—the possibility of using software and programming systems as a metalanguage for commenting on software and programming systems. The different critiques that Silvetti discusses in his analysis differ based on what codes of the underlying architectural langauge they refer to, including formal, functional and moral codes. I believe we can imagine similar critique of software that highlights one of those aspects of the system it comments on.

Possibility of a Critical Language

Many of the ideas presented in this text are the result of my search for a critical language of software. In the preceding pages, I regularly discussed an architectural idea and looked for ways in which a similar point can be (or has been) made about software. To translate critical ideas into the world of software, it is useful to reflect on the general mechanism through which the critical langauge of architecture works. To what extent are software and programming systems like architecture—and can be subjected to the same kind of criticism—and to what extent do they differ?

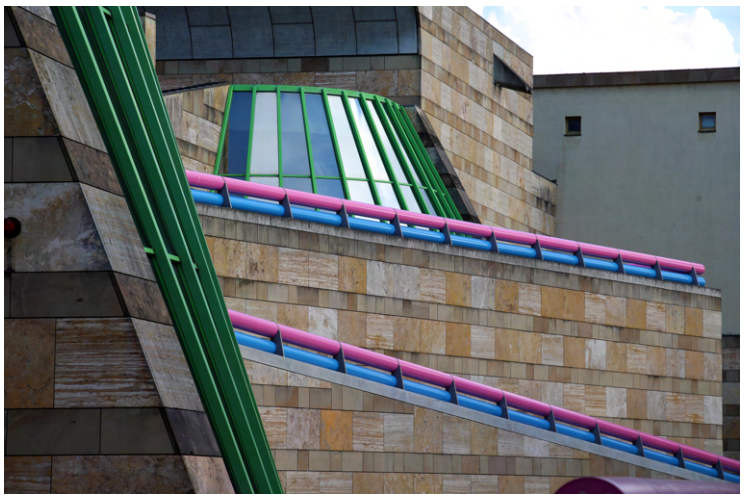


Figure 29: Addition to Neue Staatsgalerie Stuttgart, James Stirling (1984)

Charles Jencks opens his book "The Story of Post-Modernism"[166] with an answer to a question asking what is a typical post-modern building. It is useful to quote the answer at length, because it illustrates two key mechanisms at work in post-modern buildings:

> [Typical post-modern building is one] that is hybrid, one that dramatizes the mixture of opposing periods—the past, present and future—to create a miniature 'time-city'. Hence it is based on multiple codes, combing Modern universal technology and local culture, in a recognizable 'double-coding', its characteristic style. The typical Post-Modern building speaks on several levels at once, to high and low culture, and acknowledges the global situation where no single culture can speak for the entire world.

Jencks then illustrates the idea using James Stirling's post-modern addition to the Neue Staatsgalerie in Stuttgart (Figure 29):

> Its double-coding mixes Modern elements with traditional and vernacular ones, three styles sometimes compete on one facade. But the irony is that Stirling uses High-Tech decoratively, to tell the visitor how to move through this complex site. Brightly coloured steel is thus used as symbolic ornament while traditional masonry works best as temperature control: such inversions in Post-Modernism always make you smile with their knowing irony.

What is needed of software or programming system to read the multiple codes present in a post-modern system and make you smile with knowing irony? The key difficulty is that buildings have many ways through which they can express meaning that is immediately visible to anyone who encounters the building. Three styles on one facade, brightly coloured steel, false arches, upside-down stairs or broken columns are all visible external features of a building that you can see when you visit a museum or enter a house.

In contrast to architecture, most software is opaque. When you encounter it, you are typically exposed only to its functional aspects. Software systems have user interface that can be styled in various ways. Such styling can be used to make some ironical statements,

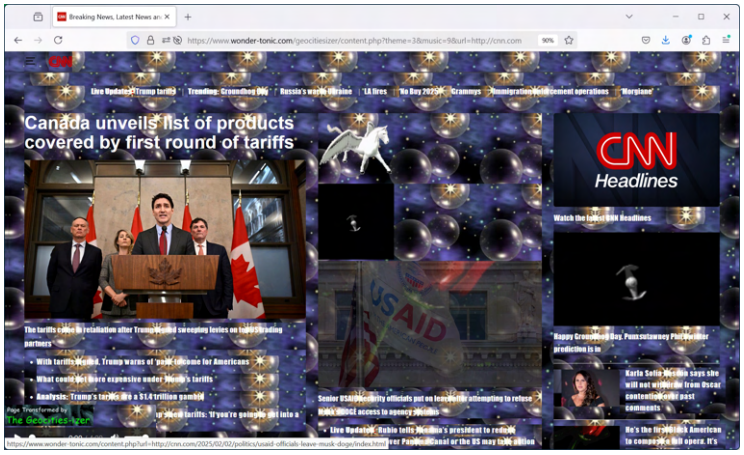


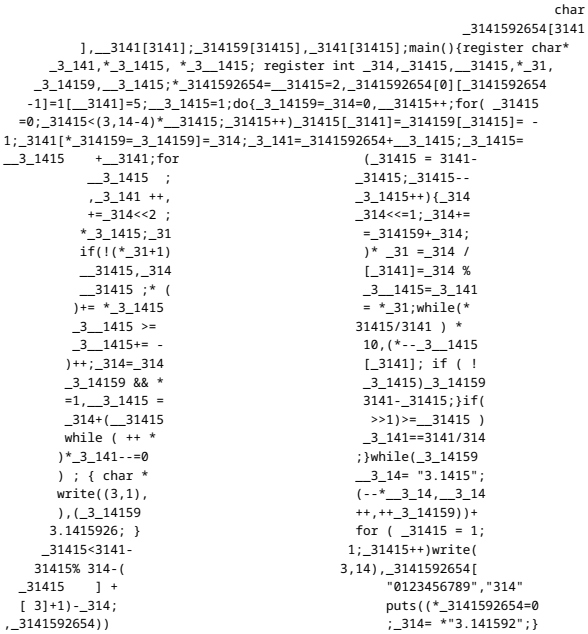
Figure 30: The CNN homepage, transformed using "The Geocities-izer" created by Mike Lacher

such as by rendering a serious web site in a style resembling the typical Geocities design (Figure 30), but this use is typically limited to toy projects and has only limited expressive power. A contemporary art gallery would not likely comission a software artist to create a contradictory, critical or ironic web page for it. (Though, perhaps it should do exactly this!)

It is worth noting that user interface is not just the visual aspect (styling) of the software system, but also the patterns of interaction that it supports. The "worst practice UI experiment" User Inyerface (Figure 10) discussed earlier consists mostly of components with a standard look, but uses them in distorted ways. More generally, the double coding can leverage the fact that there are certain established user interface patterns for certain kinds of services. Social media use a timeline, online shopping sites use a catalog with features such as filtering, a search engine prompts for a query, a file browser displays folders and documents, and so on. Using an established user interface pattern for a task it was not inteded or designed for can thus be used as a form of double coding. (Digital platforms for child adoption in the US studied by Isabelle Higgins are an alarming inadvertent example of this. The fact that the platforms adopt the structure of online shopping sites leads to a "bizarre and depressing process of catalogue shopping" for children eligible for adoption.[167] Perhaps the same double coding mechanism can be used intentionally and in a beneficial way.

The opposite extreme, in contrast to looking at the user interface, is to look at the software source code. This view is typically only accessible to experts, but it offers other interesting possibilities of employing double coding. On the one hand, the program source code is understood by the computer, which can execute the instructions (or, more precisely, the compiler or an interpreter). On the other hand, the source code can be read by a human, who interprets it, often through broader cultural associations.

There are multiple ways through which source code can express meaning to a human that is inaccessible to the computer. This includes aspects such as code formatting, variable naming and comments. Software engineers typically use those devices to aid program comprehension – and so the meaning intended for the human reader matches the meaning intended for the computer, possibly providing additional motivation or context. However, it can also be used in ironical ways to confuse the reader (Figure 31) or for artistic purposes.[168] The semantic flexibility also gives code aesthetical qualities that have been used for different purposes and are judged differently by different readers.[169]



```
                                                                    char
                                                                _3141592654[3141
        ],__3141[3141];_314159[31415],_3141[31415];main(){register char*
      _3_141,*_3_1415, *_3__1415; register int _314,_31415,__31415,*_31,
    _3_14159,__3_1415;*_3141592654=__31415=2,_3141592654[0][_3141592654
   -1]=1[__3141]=5;__3_1415=1;do{_3_14159=_314=0,__31415++;for( _31415
  =0;_31415<(3,14-4)*__31415;_31415++)_31415[_3141]=_314159[_31415]= -
1;_3141[*_314159=_3_14159]=_314;_3_141=_3141592654+__3_1415;_3_1415=
__3_1415    +__3141;for                      (_31415 = 3141-
          __3_1415  ;                      _31415;_31415--
          ,_3_141 ++,                      _3_1415++){_314
          +=_314<<2 ;                      _314<<=1;_314+=
         *_3_1415;_31                       =_314159+_314;
         if(!(*_31+1)                       )* _31 =_314 /
         __31415,_314                       [_3141]=_314 %
         __31415 ;* (                       _3__1415=_3_141
        )+= *_3_1415                        = *_31;while(*
        _3__1415 >=                        31415/3141 ) *
        _3__1415+= -                        10,(*--_3__1415
       )++;_314=_314                        [_3141]; if ( !
       _3_14159 && *                        _3_1415)_3_14159
       =1,__3_1415 =                        3141-_31415;}if(
       _314+(__31415                         >>1)>=__31415 )
       while ( ++ *                         _3_141==3141/314
      )*_3_141--=0                         ;}while(_3_14159
      ) ; { char *                         __3_14= "3.1415";
      write((3,1),                         (--*__3_14,__3_14
      ),(_3_14159                          ++,++_3_14159))+
     3.1415926; }                          for ( _31415 = 1;
    _31415<3141-                          1;_31415++)write(
   31415% 314-(                          3,14),_3141592654[
  _31415    ] +                                "0123456789","314"
  [ 3]+1)-_314;                                puts((*_3141592654=0
,_3141592654))                                 ;_314= *"3.141592";}
```

Figure 31: The International Obfuscated C Code Contest entry by Roemer B. Lievaart from 1989.

At a higher-level of abstraction, we may be able to find double-coding in the internal structure of software. Here, I refer to software aspects such as architecture (is it microservice-based, monolithic, composed of different layers and components), as well as data structures used (to what degree is there a fixed structure for the data and relationships).[170] Those aspects are typically hidden from the user and are not always easy to reconstruct even for a programmer. However, a system that would make such structure more apparent (just like Centre Pompidou exposes its infrastructure) could use it to express meaning.

It may be that our ability to use double coding and irony in the design of typical software systems is limited. There is only so much that we can say through the user interface and interaction patterns and there are only so many people who will venture to investigate the source code. However, there certainly are kinds of software systems that have greater expressive powers. This is why the focus of this text has often been on programming languages and systems. As we have seen, a programming language can exhibit double coding and irony in a range of ways, ranging from the choice of features (combining contradictory formal structures) to the use of syntax with particular association (adding a popular syntax to a non-mainstream language).

Transparency and Methodological Freedom

To provide a tentative conclusion, I believe that the world of software and programming systems desparately needs two things. The first is a greater transparency. It should be possible to see inside software systems to a much greater degree. This will let users understand (and perhaps even change) how software works, but it would also enable more active critical discourse about software. The second is methodological freedom. Many interesting architectural ideas first emerged in more experimental contexts and, perhaps, if we were building software not only for immediate practical commercial use, we would be able to come up with innovative software structures.

There are already systems that hint at how the greater transparency may look, but for one reason or another, they have not achieved their ultimate objectives. The free software manifesto argues for the "freedom to study how the program works, and change it so it does your computing as you wish".[171] This may have been the case about free software in the 1980s when most users were also C programmers. Today, in practice, even if you are using free software, you have a little chance of understanding how it works, much less changing it, due to its complexity.

Programming systems and environments based on Smalltalk provide greater transparency thanks to the fact that program execution is not distinct from the programming environment. As such, the user of an application can inspect the structure of the system and navigate to the source code. The Smalltalk designers imagined that users would start by using existing applications, but then gradually learn how to tweak and adapt them, create new ones and even modify the system itself.[172] Although Smalltalk inspired virtually all modern object-oriented langugages, very few of them retained this ability.

Finally, the 1990s era of web also afforded greater transparency. As discussed above, it was possible to view source code of existing web pages, extract interesting JavaScript snippets and reuse them. This supported the rise of the creative vernacular web. However, modern web applications are nothing like this. Their source code and internal structure is hidden—partly to protect intellectual property and partly for engineering reasons (large modern web applications are composed of components that are compiled together and minimized for efficiency).

I do not know how to make modern software development transparent in the sense in which it was transparent in the early days of free software, object-oriented programming and the web, but I'm convinced that this is something that we need in order to create software that serves its users—and also to create software that supports self-reflective critical discourse about software.

The second thing that I argued for is greater methodological freedom. If we try to express software critique only through regular, commercial software systems built with a tight budget, we are inevitably bound to fail. Or, rather, what we can "say" through such software will be very limited. It seems that buildings have greater potential for double-coding and expressivity than software, but it is not an accident that many of the examples I mentioned throughout this text were not ordinary commercial buildings with tight budget. (An exception from the rule would be Venturi's Guild House, which combined ordinary form with decorative historical references. The economy of the project, built as a "decorated shed", was a notable part of Venturi's critique of modernist architecture.)

The examples that were featured prominently as my references included museums, public buildings, pavilions, parks, monuments, luxurious villas, but also unrealized plans for buildings and, notably, projects that had the structure of an architectural plan, but were never intended to be realized. All of those provided additional room for criticism than an ordinary commercial building would. Perhaps, if we want to express critical ideas through software, we also need to do so through special kinds of software.

What if the critique of the closed nature of software came in the form of a radically open and accessible public service software? What if technical documentation for a fictional operating system illustrated an alternative to the system consisting of isolated inflexible apps? What if we celebrated landmark programming systems and their creators by questioning their design decisions, say by creating an irregular freeform spreadsheets?

Notes

[1]patterns, RPG, Steenson
[2]p26
[3]Alexander Eisenmann debate https://arahovsepyan.com/eisenmanalexander
[4]Agreeing with Eisenmann in the debate
[5]Oppositions – p52, p55
[6]Idea from Oppositions p377, See also Korman “The Architecture of the Facade” - for more on columns
[7]Wootton
[8]Also conservative “Executive Order on Promoting Beautiful Federal Civic Architecture” – Trump’s administration (2020)
[9]Unwin - Twenty-Five Buildings Every Architect Should Understand
[10]Krul - Adolf Loos and the Doric Order
[11]Jencks, p183
[12]Branscombe - Hans Hollein and Postmodernism
[13]Oppositions, p182
[14]Oppositions 377, also Venturi introduction
[15]Jencks, p56
[16]ref Abstracting craft p96; ref Joel - the other part of the basic structure is how change is described
[17]Memory models blog
[18]Dan Maharry, TypeScript Revealed, 2013
[19]http://www.charlespetzold.com/etc/CSAML.html
[20]Cox, Speaking Code
[21]Parnas, On the criteria; also reflections in https://link.springer.com/chapter/10.1007/978-3-642-59412-0_25
[22]GPII Nexus, my article on architecture, Convivial Design Heuristics for Software Systems
[23]GPII nexus
[24]But this has limits, see my talk.
[25]suggested by Clark and Basman
[26]this is already possible via reflection or in image-based systems
[27]c.f. antifragile
[28]Gehry’s residence, Vanna Venturi house
[29]Jencks, 119
[30]vagni teren
[31]see debate
[32]Oppositions, x
[33]Oppositions, 202
[34]Algol
[35]Formal basis, p293
[36]Autonomy and the Will to the Critical - Eisenman
[37]Oppositions, p219
[38]debate
[39]Chora L Works
[40]Kipnis in Chora L works, p137
[41]Deconstruction in Architecture, at Tate and Deconstructivist Architecture at MoMA, both 1988.
[42]See Frank Gehry, Architect: The Art of Architecture (Guggenheim Museum Publications)
[43]The secret life of buildings: An American mythology for modern architecture
[44]Deconstruction in Architecture (Papadakis, ed.) - p18
[45]Callaghan, M. (2020). Empathetic Memorials. Palgrave Macmillan Memory Studies.
[46]https://eisenmanarchitects.com/Berlin-Memorial-to-the-Murdered-Jews-of-Europe-2005
[47]https://eisenmanarchitects.com/Berlin-Memorial-to-the-Murdered-Jews-of-Europe-2005
[48]And even houses built to question the humanist focus of architecture sometimes found their satisfied owner. https://www.nytimes.com/2002/10/10/garden/house-proud-a-white-elephant-reincarnated.html
[49]Oppositions, 219
[50]cite
[51]debate
[52]Patterns of Software
[53]cite
[54]Twitter and tear gas

[55] debate
[56] some kind of citation
[57] http://www.madore.org/~david/programs/unlambda/
[58] http://www.madore.org/~david/programs/unlambda/
[59] https://learn.microsoft.com/en-us/cpp/cpp/lambda-expressions-in-cpp
[60] A Z combinator, from https://rosettacode.org/wiki/Y_combinator
[61] For Gehry, see https://www.nytimes.com/2007/11/07/us/07mit.html
[62] Web archive of http://www.boston.com/ae/theater_arts/articles/2004/04/25/dizzying_heights/
[63] Jencks, p172 about Fuksas, New Milan Trade Fair
[64] See http://www.nytimes.com/2014/04/19/technology/heartbleed-highlights-a-contradiction-in-the-web.html
[65] Jackson, p15
[66] p30
[67] zuboff
[68] See https://www.awo.agency/blog/tanya-o-carroll-v-meta-landmark-case-to-stop-facebook-spying-on-us/, claim https://www.awo.agency/files/ocarroll-v-meta-bundle.pdf
[69] cite
[70] notes, p15
[71] dtto, p20
[72] edited, rudofsky p3 - criticises our condescending narrative based on talking about exotic countries.
[73] Notes, p58
[74] Sulivan
[75] Julia Jamrozik and Coryn Kempster, Growing up Modern. Childhoods in Iconic Homes, Basel, Birkhäuser, 2021, 83; quoted in Ana Tostões - Modern Heritage Reuse. Renovation. Restoration (2022, Birkhäuser)
[76] Isokon, p60, also note this was theme of the 1929 CIAM congress
[77] dtto, p59
[78] Notes, p24
[79] p134
[80] See https://tomasp.net/blog/2022/timeless-way/
[81] he does not agree and also worked closely with Denise Scott Brown
[82] Complexity and Contradiction, p16
[83] Complexity and contradiction, p16; citing Alexander's Notes
[84] Complexity, p16
[85] p28
[86] cite
[87] p.xi (preface)
[88] p6
[89] p20
[90] p13
[91] Oppositions, p178
[92] Learning, p102
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[94] https://eisenmanarchitects.com/Fin-D-Ou-T-Hou-S-1983
[95] dtto
[96] Oppositions, p67
[97] Some links to relevant work https://en.wikipedia.org/wiki/Olia_Lialina
[98] Digital Folklore, p19
[99] see "Welcome to the web: The online community of GeoCities during the early years of the World Wide Web" chapter
[100] Folklore, p24
[101] And it was also mascuiline - see for example https://dl.acm.org/doi/pdf/10.1145/3451227
[102] c.f cultures book
[103] HAKMEM
[104] Cultures of Programming
[105] See cultures, NATO conference
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[107] Rudofsky, p3 and p4
[108] e.g. lo-tek book
[109] See also complementary science, BASIC; some work in this area e.g. people's history, dot-com design.

[110] on rotation see https://nideffer.net/classes/135-09-F/readings/rolling_stone.html, for more also spacewar chapter in you are not expected to understand this.
[111] An Accidental Masterpiece: Mies van der Rohe's Barcelona Pavilion
[112] Socio-PLT: principles for programming language adoption
[113] Rudofsky, p4
[114] socio-plt
[115] cite
[116] Brooks, p44
[117] dtto, p44
[118] Brooks, p44
[119] documented in cultures; ensmenger etc.
[120] cite
[121] report in magazine http://www.bitsavers.org/magazines/Computers_And_Automation/196904.pdf, p30
[122] cite
[123] oppositions, p360
[124] Brand, p157
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[127] Programming as Architecture, Design, and Urban Planning
[128] Scott,p261
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[130] p6
[131] Complexity, p25
[132] From "A History of Erlang"
[133] p42
[134] Directions https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2019/p0939r2.pdf
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[136] Directions
[137] Thriving in a Crowded and Changing World: C++ 2006–2020
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[139] Contradiction, p109
[140] c.f. the mu project?
[141] https://reasonml-old.github.io/guide/what-and-why
[142] cite
[143] Man-Month anniversary ed, p181
[144] Man-Month anniversary ed, p197
[145] Vegas, p6
[146] The specific snippet comes from the source code of TypeScript 2.0, but the features existed in earlier version. In later versions of TypeScript, the same is achieved using `keyof HTMLElementTagNameMap` instead.
[147] p6
[148] Some references, some criticism of this
[149] Formal basis, p11
[150] CSP paper; also see "A Brief History of Process Algebra".
[151] CSP paper
[152] Turner, "Some History of Functional Programming Languages"
[153] See https://programming-journal.org/2020/4/8/
[154] Imperative FP
[155] Imperative functional programming
[156] From Formalism to Weak Form: The Architecture and Philosophy of Peter Eisenman, p33
[157] https://www.archdaily.com/63267/ad-classics-house-vi-peter-eisenman
[158] paper
[159] cite
[160] cite
[161] Weapons of Math Destruction, Algorithms of Oppression, The Age of Surveillance Capitalism, Twitter and Tear Gas
[162] cite
[163] Oppositions, p372
[164] Oppositions p376

[165] Oppositions, p376
[166] cite
[167] https://journals.sagepub.com/doi/10.1177/14614448231156852
[168] see `./code -poetry` book
[169] Depaz; see also 10 PRINT book, critical code studies, Foo bar paper
[170] Joel's goblin example
[171] manifesto
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